WRF-ARW Research to Operations Update: The Rapid-Refresh (RAP) version 4, High-Resolution Rapid Refresh (HRRR) version 3 and Convection-Allowing Ensemble Prediction

13 June 2017

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NOAA/ESRL/GLOBAL SYSTEMS DIVISION

RAP/HRRR: Hourly-Updating Weather Forecast Suite

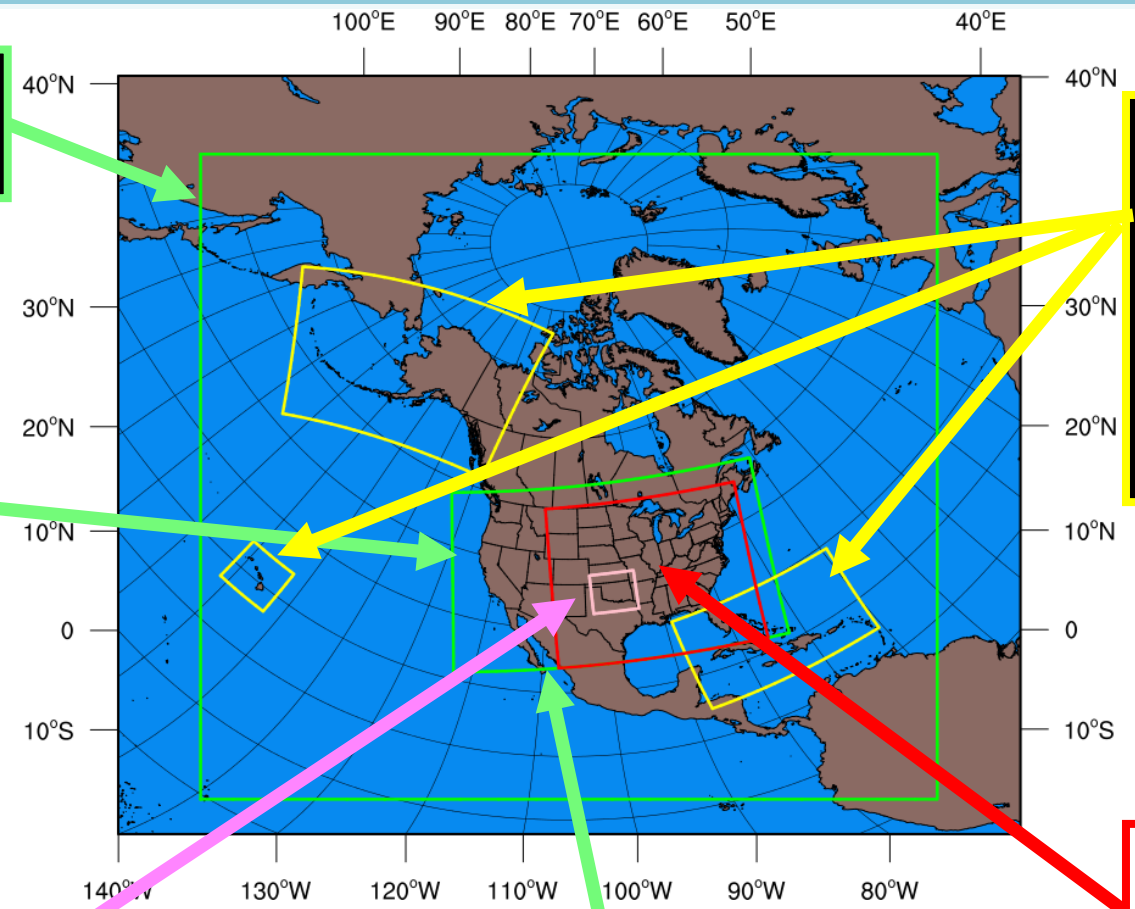
13-km Rapid Refresh (RAPv4) – to 39h (Feb 2018)

Initial & Lateral Boundary Conditions

3-km High-Resolution Rapid Refresh (HRRRv3) – to 36h (Feb 2018)

Initial & Lateral Boundary Conditions

750-m HRRR nest Scale-aware Physics Testing (ongoing)



3-km High-Resolution Rapid Refresh Alaska, Hawaii and Puerto Rico Testing (HRRR-AK, HRRR-HI, HRRR-PR) Experimental (ongoing)

3-km High-Resolution Time Lagged Ensemble (HRRR-TLE)

3-km HRRR-Smoke (VIIRS fire data)

3-km Storm-Scale Ensemble Analysis and Forecast (HRRRE) 55% CONUS HRRR Experimental (ongoing)

RAP/HRRR Implementation History

Operational Implementations

01 May 2012
- RAPv1: Adoption of GSI, WRF-ARW and unified post
- Enabled use of community-developed software

25 Feb 2014
- RAPv2: Hybrid EnKF-3DVar data assimilation
- Significant improvement in upper-air forecasts

30 Sep 2014
- HRRRv1: 3-km Radar DA in WRF-ARW
- Significant improvement in convective forecasts

23 Aug 2016
- RAPv3/HRRRv2: Aerosol Thompson MP, improvements to MYNN PBL, RUC LSM, RRTMG Rad, Grell-Freitas cumulus
- Significant improvement in surface forecasts

13 Feb 2018
- RAPv4/HRRRv3: Hybrid Vertical Coordinate, Eddy Diffusivity Mass Flux PBL
- Reduction in short-lead biases and improved mesoscale environment

Extended Forecast Lengths
RAP: 03z, 09z, 15z, 21z 21 hrs → 39 hrs
RAP: All other hourly cycles remain 21 hrs
HRRR: 00z, 06z, 12z, 18z 18 hrs → 36 hrs
HRRR: All other hourly cycles remain 18 hrs

OCONUS Domains
HRRR-Alaska:
Every 3 hrs to 18 hrs
Every 6 hrs to 36 hrs
HRRR-Hawaii: ??

RAP/HRRR: Hourly-Updating Weather Forecast Suite

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Initial & Lateral Boundary Conditions

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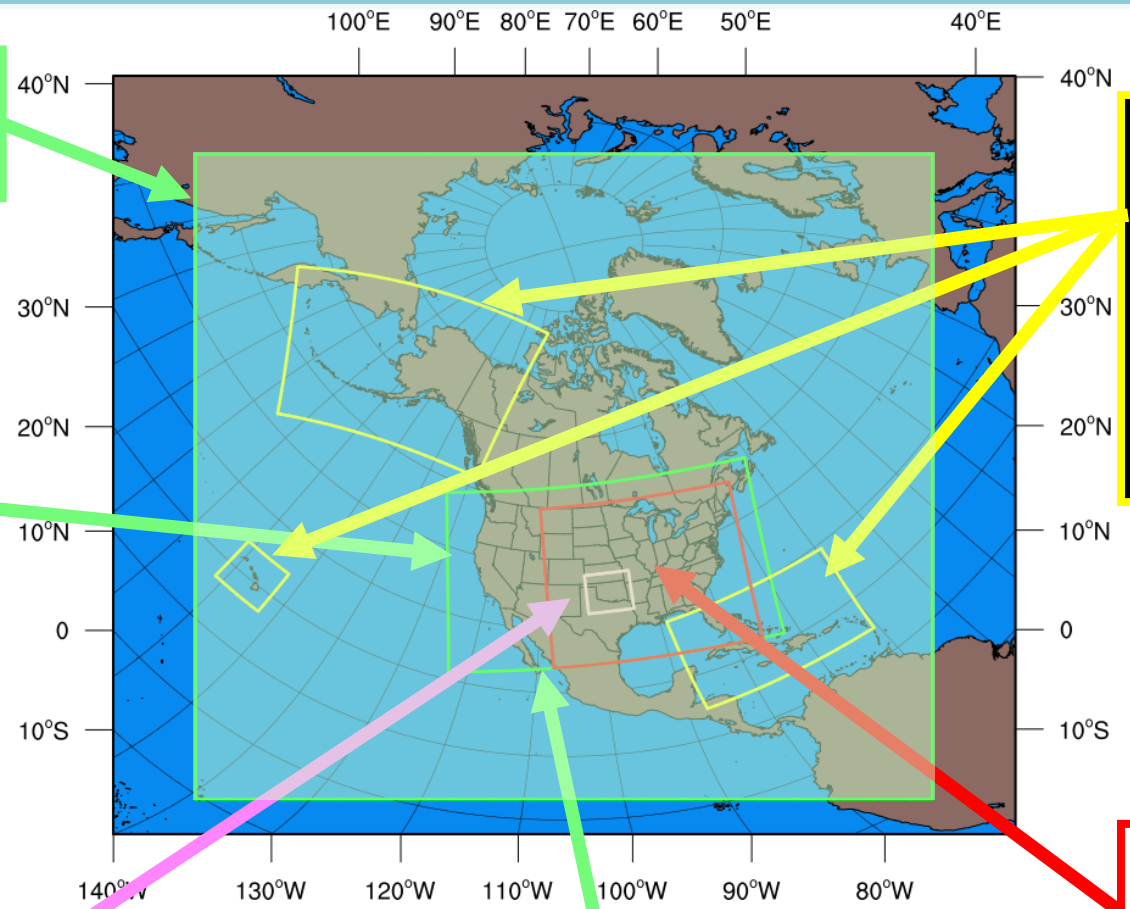

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3-km HRRR-Smoke (VIIRS fire data)

3-km Storm-Scale Ensemble Analysis and Forecast (HRRRE) 55% CONUS HRRR Experimental (ongoing)

RAPv4/HRRRv3 Change Highlights

	Model	Data Assimilation
RAPv4 (13 km)	**WRF-ARW v3.8.1+ incl. physics changes** ***Physics changes (12 changes):*** Thompson microphysics – improved upper-level clouds GF Convective update – more optimal precip bias MYNN PBL update – better sub-grid clouds, meso env LSM update – 15" MODIS data – better lower boundary Refined roughness lengths over various land use types ***Numerics changes (3 changes):*** Improved terrain (cell avg) – better winds /turbulence Hybrid vertical coordinate from NCAR – better meso env Full geometric diffusion – better winds/temp in terrain	Merge with GSI trunk – last updated in May 2017 ***New Observations for assimilation (4 changes):*** NCEP new VAD wind retrievals AMVs over land and TAMDAR Add IASI, CrIS, SEVIRI radiances ***Assimilation Methods (9 changes):*** Revised PBL pseudo-obs – reduce RH bias More ensemble weight in hybrid DA (0.85/0.15) METAR/GOES cloud consistent (<1200m AGL) Cloud building – smaller qc/qi – more retention Reduced latent heating – improved precip bias
HRRRv3 (3 km)	**WRF-ARW v3.8.1+ incl. physics changes** ***Physics changes (12 changes):*** Thompson microphysics – improved upper-level clouds MYNN PBL update – better sub-grid clouds, meso env LSM update – 15" MODIS data – better lower boundary Refined roughness lengths over various land use types Gravity wave drag (RAP and HRRR) – better winds ***Numerics changes (2 changes):*** Hybrid vertical coordinate from NCAR – better meso env Full geometric diffusion – better winds/temp in terrain	***New Observations for assimilation (5 changes):*** NCEP new VAD wind retrievals AMVs over land and TAMDAR Radar radial velocity and lightning ***Assimilation Methods (9 changes):*** Revised PBL pseudo-obs – reduce RH bias More ensemble weight in hybrid DA (0.85/0.15) METAR and GOES cloud consistent (<1200 m AGL) Cloud building – smaller qc/qi – more retention

RAPv4/HRRRv3 Summary of Changes

Operational RAPv3/HRRRv2

Model	Run at:	Domain	Grid Points	Grid Spacing	Vertical Levels	Vertical Coordinate	Pressure Top	Boundary Conditions	Initialized
RAP	GSD, NCO	North America	953 x 834	13 km	50	Sigma	10 mb	GFS	Hourly (cycled)
HRRR	GSD, NCO	CONUS	1799 x 1059	3 km	50	Sigma	20 mb	RAP	Hourly (pre-forecast hour cycle)

Model	Version	Assimilation	Radar DA	Radiation LW/SW	Microphysics	Cumulus Param	PBL	LSM
RAP	WRF-ARW v3.6+	GSI Hybrid Ensemble to 0.75	13-km DFI	RRTMG/ RRTMG	Thompson Aerosol v3.6	GF + Shallow	MYNN v3.6	RUC v3.6
HRRR	WRF-ARW v3.6+	GSI Hybrid Ensemble to 0.75	3-km 15-min LH	RRTMG/ RRTMG	Thompson Aerosol v3.6	None	MYNN v3.6	RUC v3.6

Model	Horiz/Vert Advection	Scalar Advection	Upper-Level Damping	Diffusion Option	6th Order Diffusion	SW Radiation Update	Land Use	MP Tend Limit	Time-Step
RAP	$5^{th}/5^{th}$	Positive-Definite	w-Rayleigh 0.2	Simple (1)	Yes 0.12	20 min	MODIS Seasonal	0.01 K/s	60 s
HRRR	$5^{th}/5^{th}$	Positive-Definite	w-Rayleigh 0.2	Simple (1)	Yes 0.25	15 min with SW-dt	MODIS Seasonal	0.07 K/s	20 s

RAPv4/HRRRv3 Summary of Changes

Upcoming RAPv4/HRRRv3

No Change in CONUS Domains

Changed components for RAPv4/HRRRv3.

Newer Model Version
with hybrid vert coord
More Ensemble Weight
Advanced Physics Suite

Seasonal Vegetation Fraction/Leaf Area Index

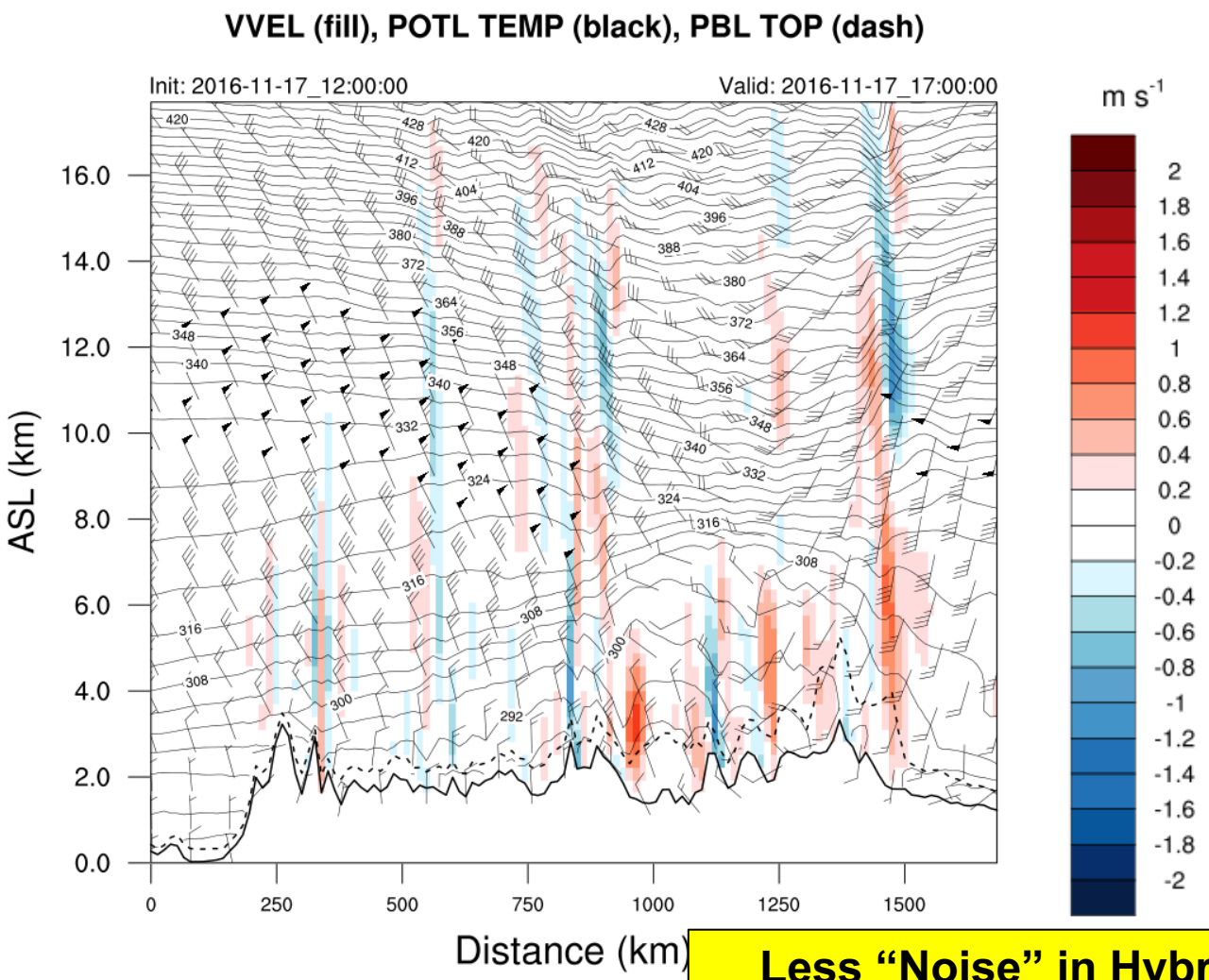
Model	Run at:	Domain	Grid Points	Grid Spacing	Vertical Levels	Vertical Coordinate	Pressure Top	Boundary Conditions	Initialized
RAP	GSD, NCO	North America	953 x 834	13 km	50	Sigma-Isob Hybrid	10 mb	GFS	Hourly (cycled)
HRRR	GSD, NCO	CONUS	1799 x 1059	3 km	50	Sigma-Isob Hybrid	20 mb	RAP	Hourly (pre-forecast hour cycle)

Model	Version	Assimilation	Radar DA	Radiation LW/SW	Microphysics	Cumulus Param	PBL	LSM
RAP	WRF-ARW v3.8.1+, hyb	GSI Hybrid Ens to 0.85, better cloud	13-km DFI, ½ Strength	RRTMG/ RRTMG	Thompson Aerosol v3.8.1	GF + Shallow	MYNN v3.8.1	RUC v3.8.1
HRRR	WRF-ARW v3.8.1+, hyb	GSI Hybrid Ens to 0.85, better cloud	3-km 15-min LH	RRTMG/ RRTMG	Thompson Aerosol v3.8.1	None	MYNN v3.8.1	RUC v3.8.1

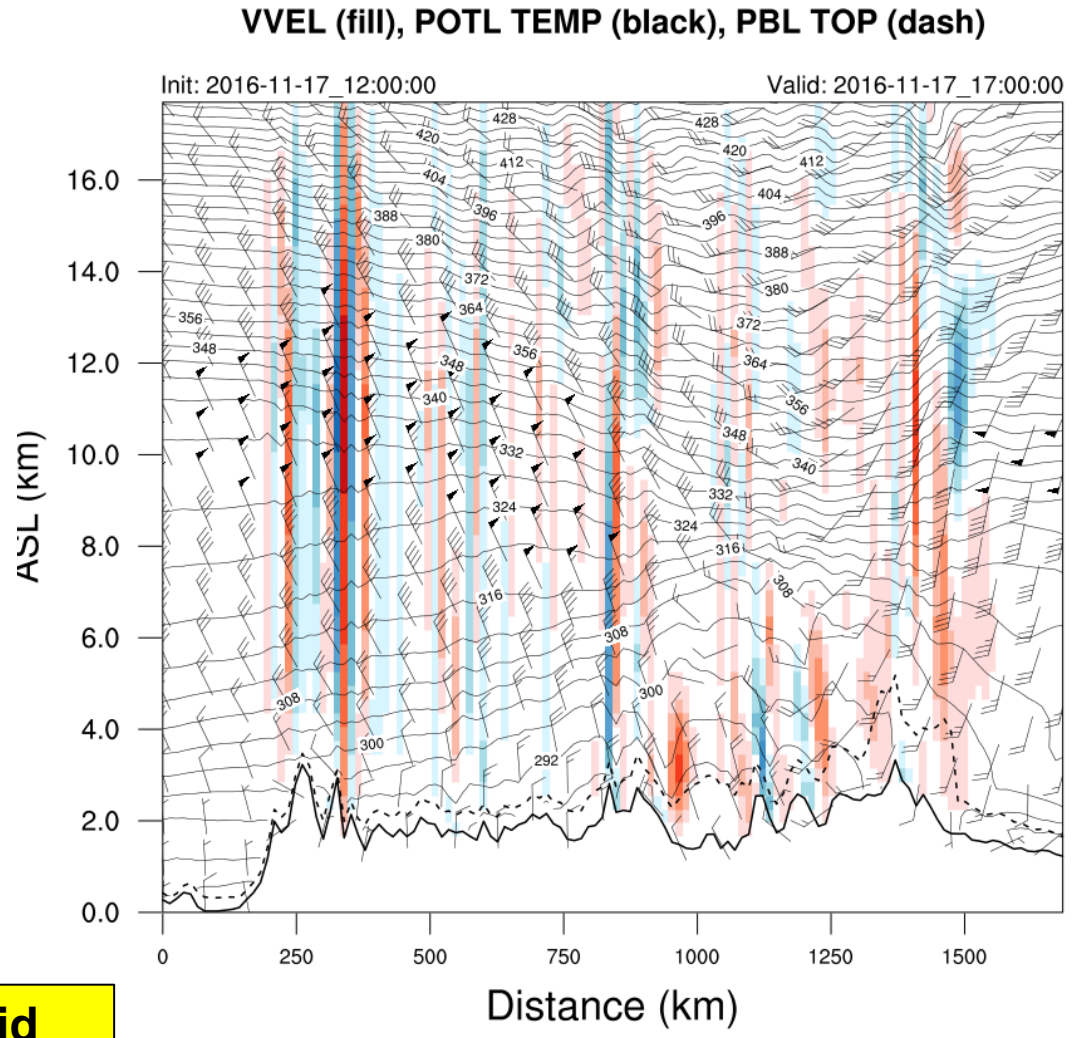
Model	Horiz/Vert Advection	Scalar Advection	Upper-Level Damping	Diffusion Option	6th Order Diffusion	SW Radiation Update	Land Use	MP Tend Limit	Time-Step
RAP	5th/5th	Positive-Definite	w-Rayleigh 0.2	Full (2)	Yes 0.12	20 min	MODIS Seasonal	0.01 K/s	60 s
HRRR	5th/5th	Positive-Definite	w-Rayleigh 0.2	Full (2)	Yes 0.25	15 min with SW-dt	MODIS Seasonal	0.07 K/s	20 s

New RAP/HRRR Vertical Coordinate

Hybrid coordinate



Terrain-following coordinate



Less "Noise" in Hybrid

RAP RMSE Upper-Air Winter (Three Weeks Jan 2017)

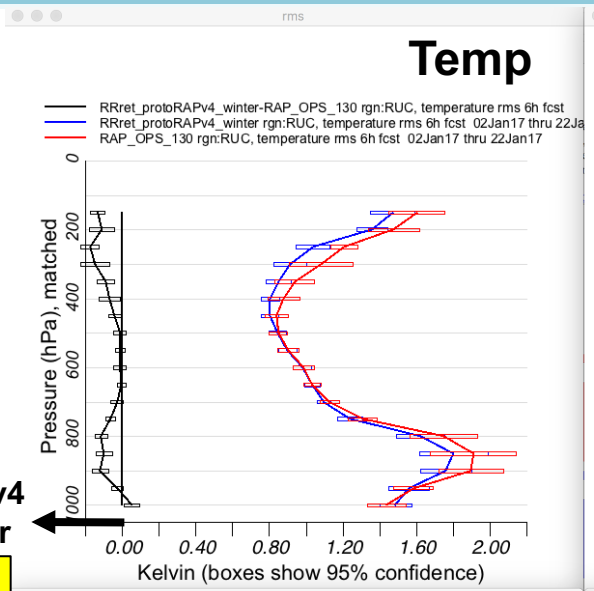
RAPv4
RAPv3 (ops)
RAPv4-RAPv3

6 hr

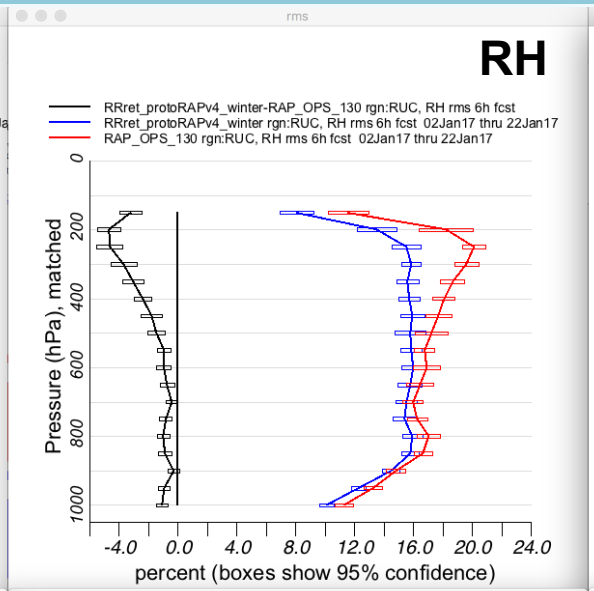
Full Tropospheric Improvements

12 hr

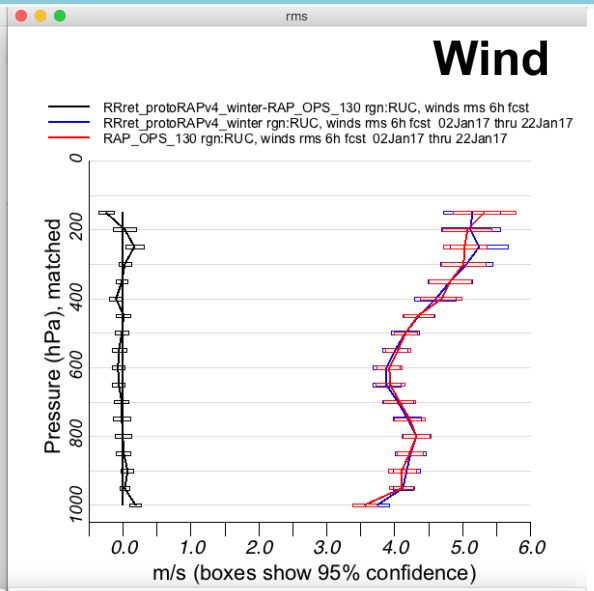
Temp



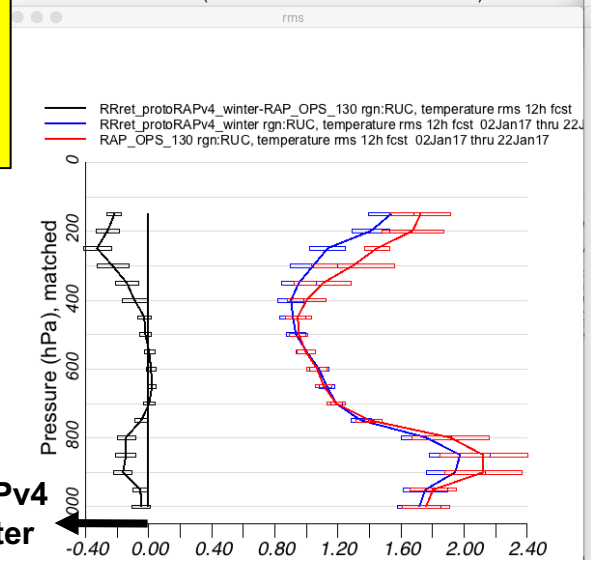
RH

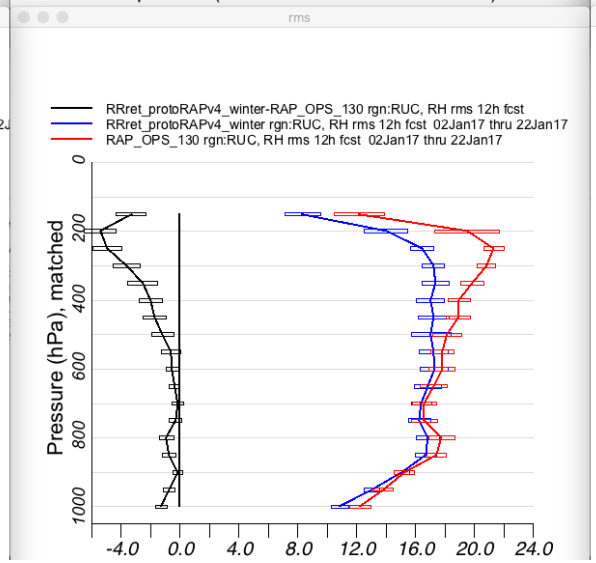


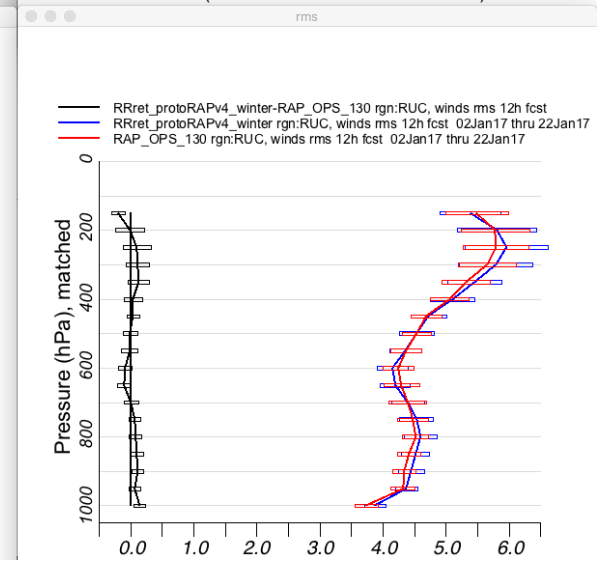
Wind



RAPv4 better







RAPv4 better

RAP BIAS Upper-Air Winter (Three Weeks Jan 2017)

RAPv4

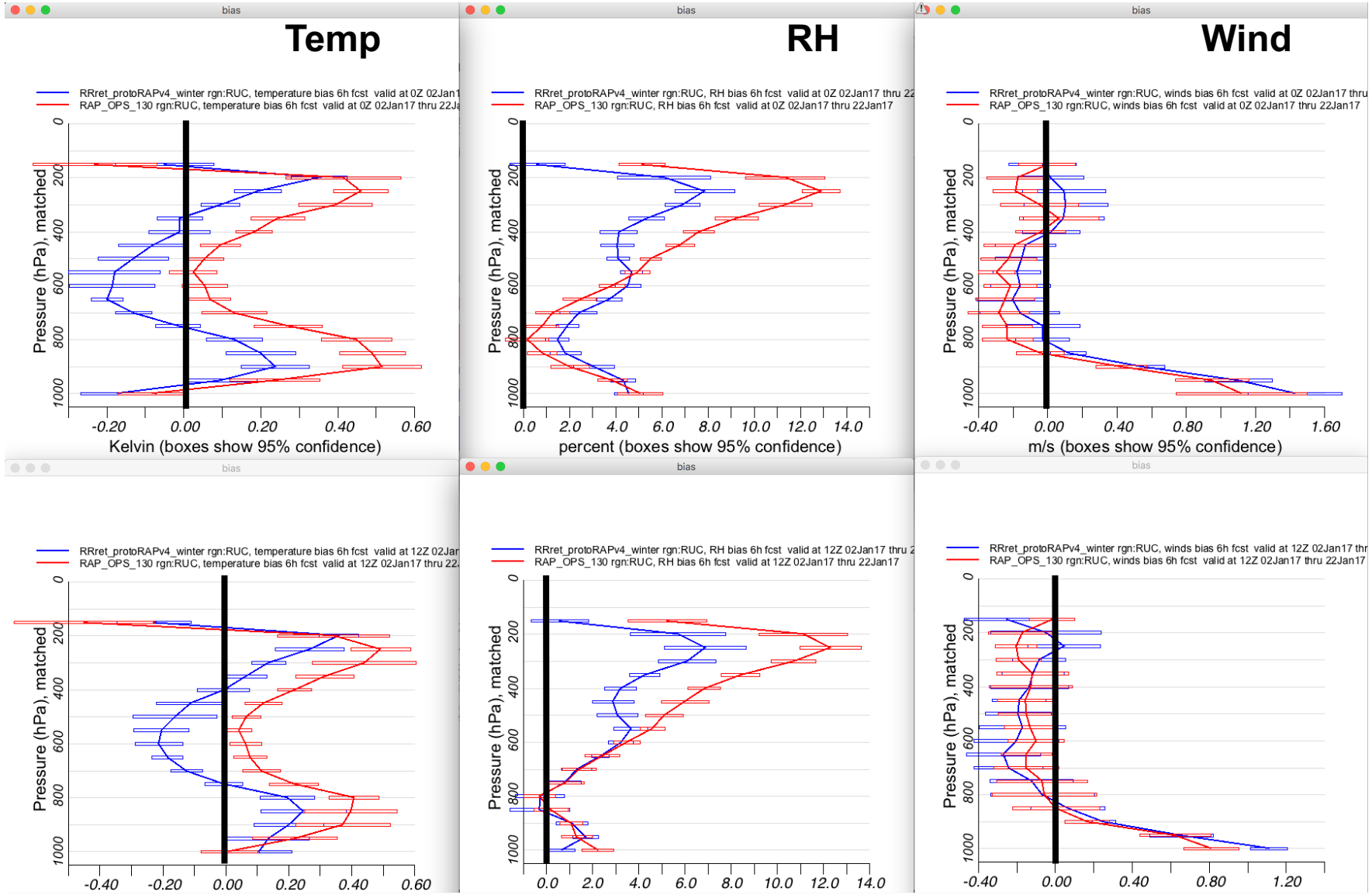
RAPv3 (ops)

6 hr fcsts

00 UTC

Reduced RH Bias Aloft

12 UTC



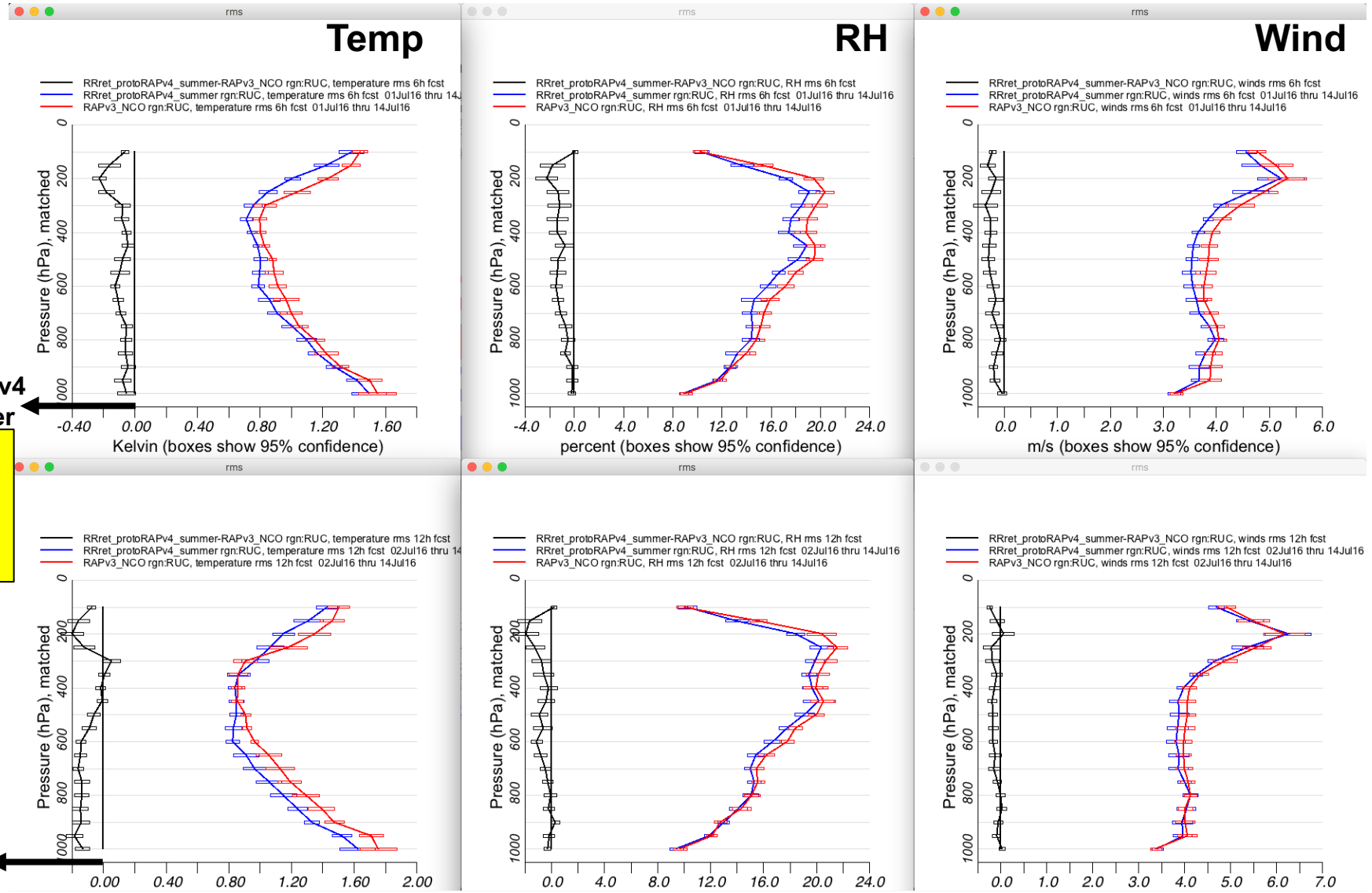
RAP RMSE Upper-Air Summer (Three Weeks Jul 2016)

RAPv4
RAPv3 (ops)
RAPv4-RAPv3

6 hr

Full Tropospheric Improvements

12 hr



RAP BIAS Upper-Air Summer (Three Weeks Jul 2016)

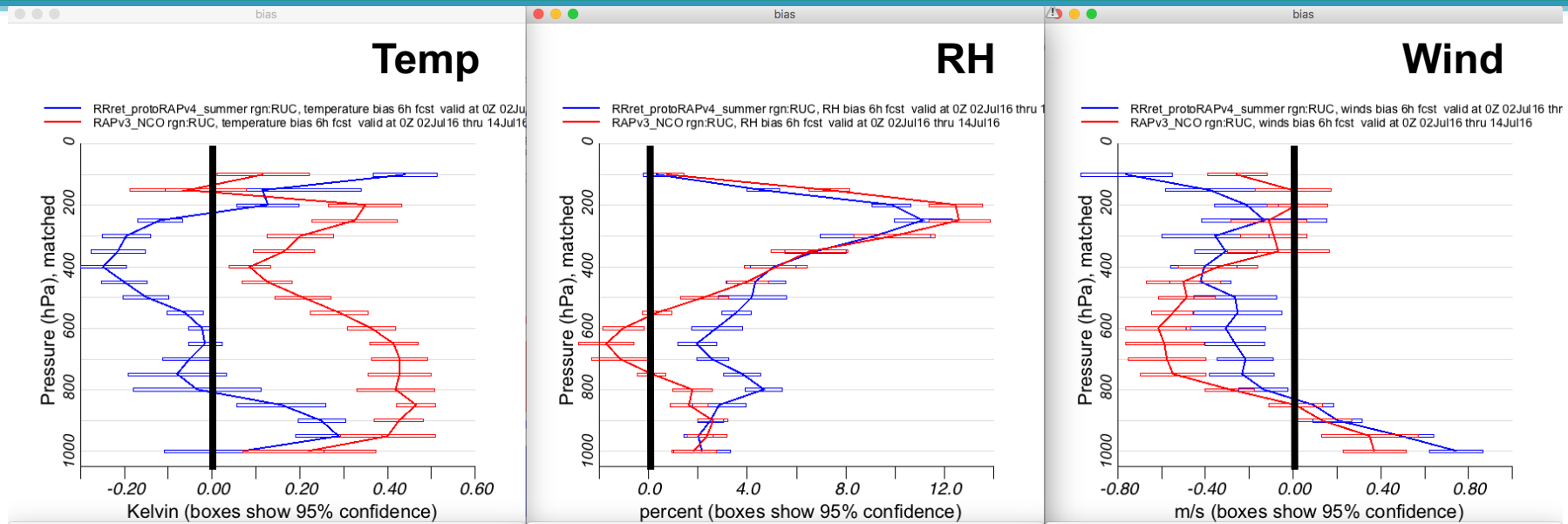
RAPv4

RAPv3 (ops)

6 hr fcsts

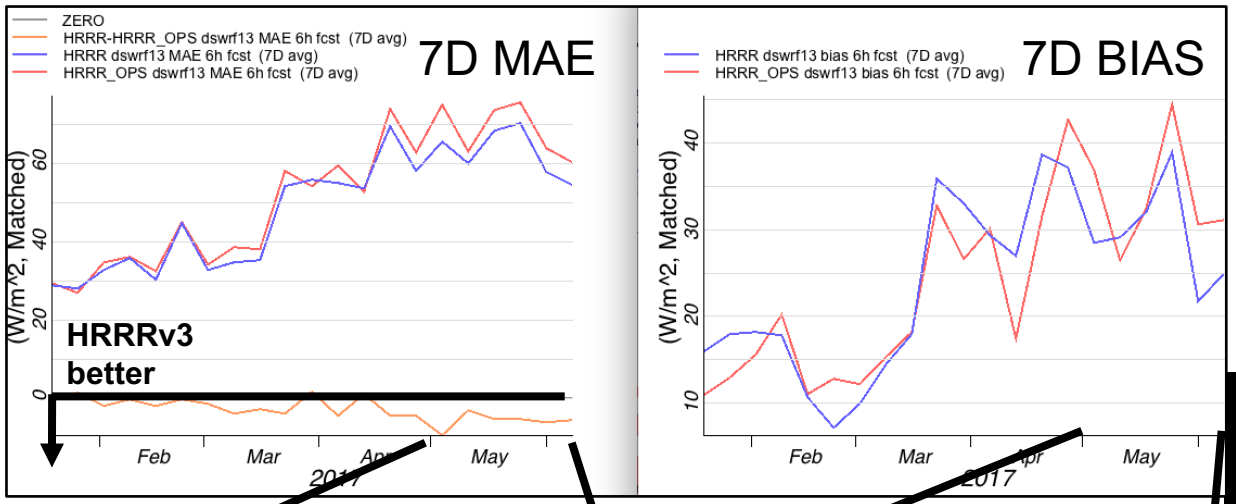
00 UTC

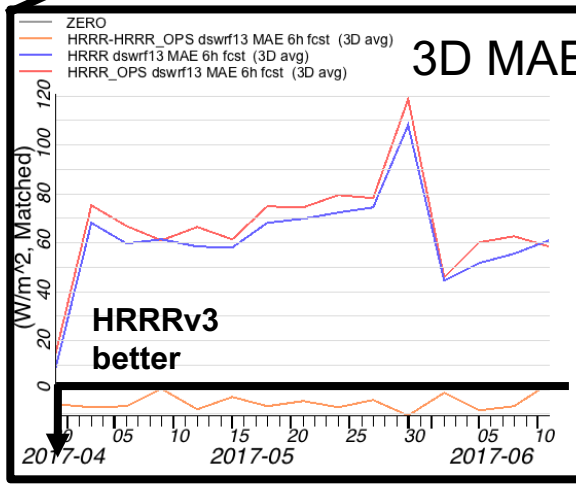
12 UTC

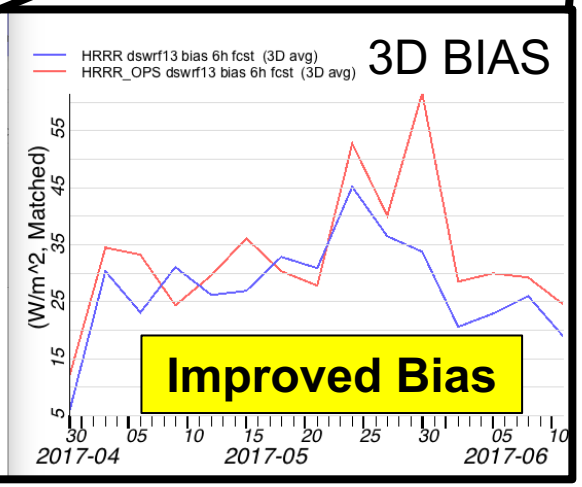


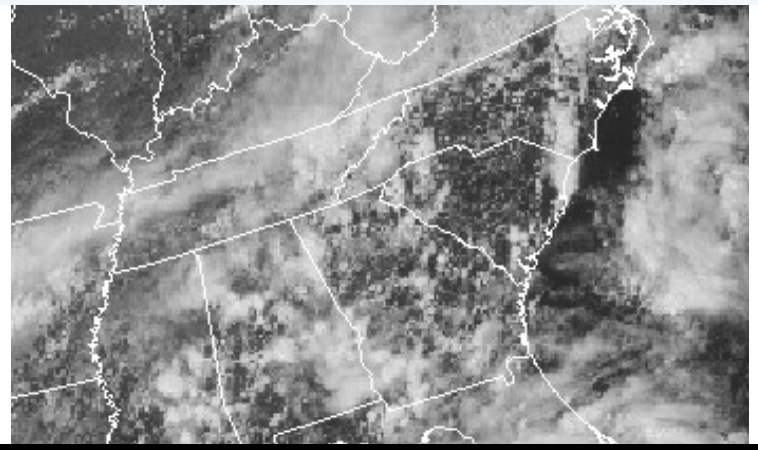
RAP/HRRR Improved Subgrid Cloud Effects

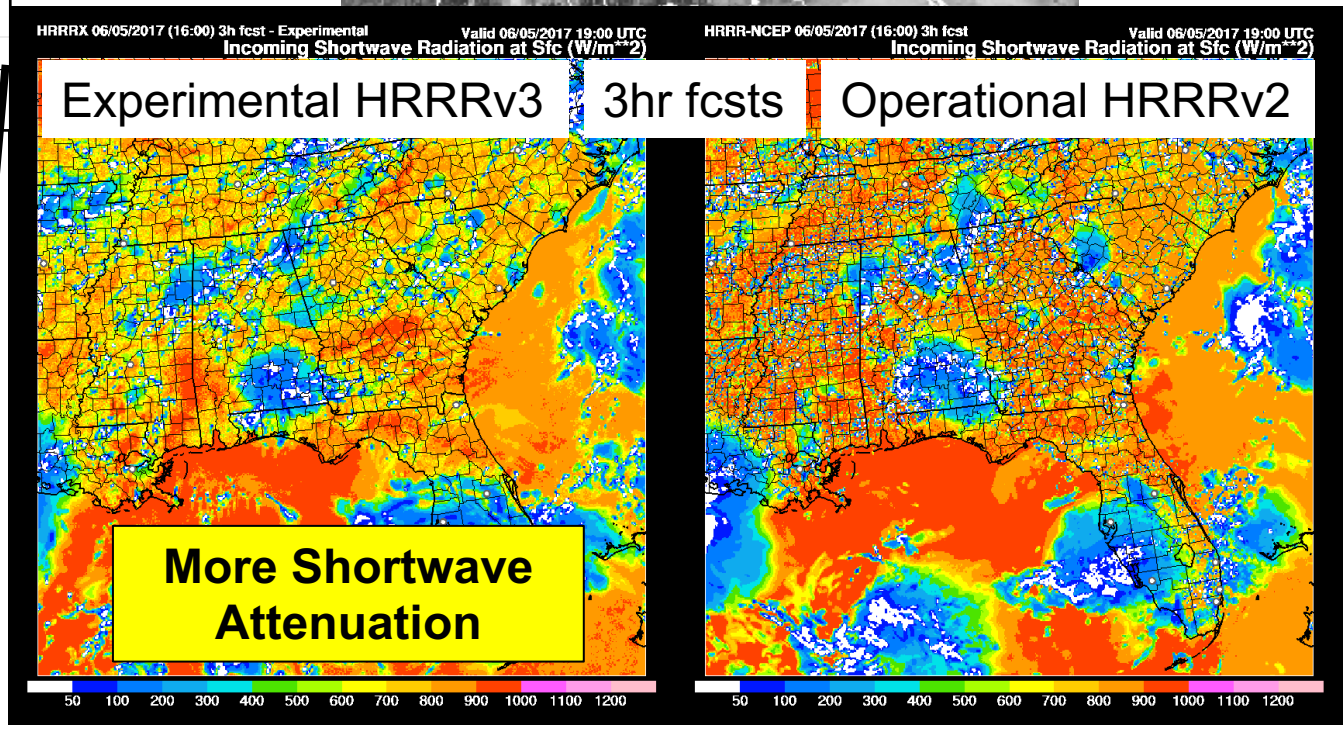
SURFRAD/SOLRAD DSWRF 6hr Fcst Verification











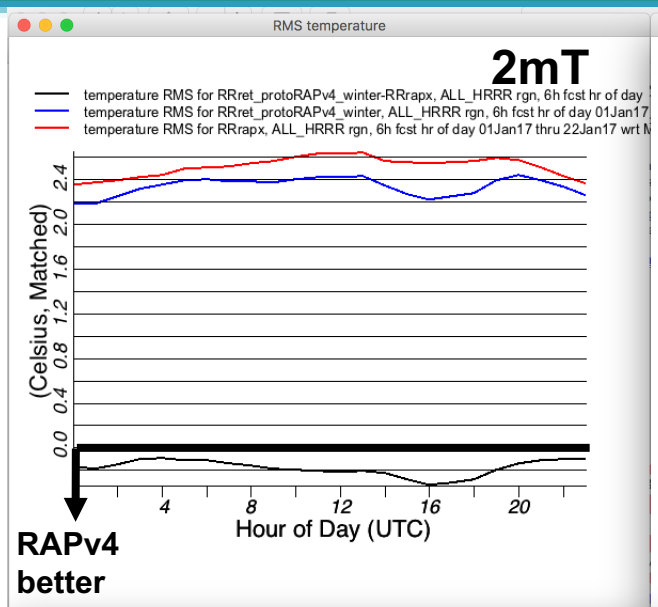
RAP RMSE Surface Winter (Three Weeks Jan 2017)

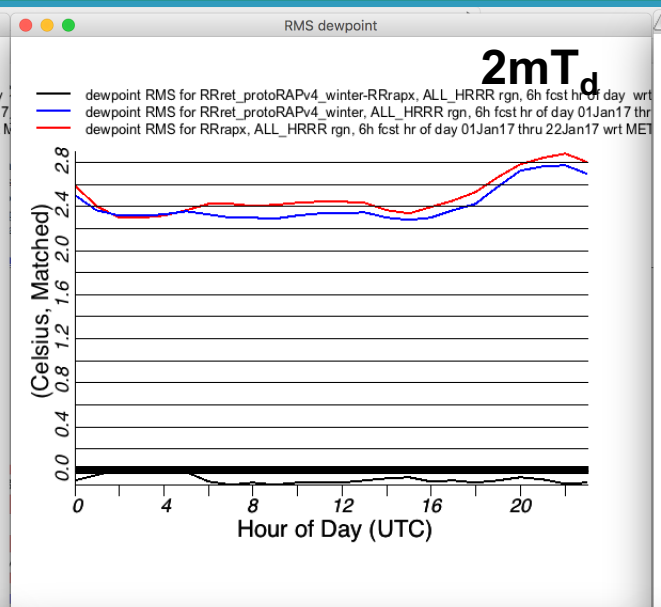
RAPv4
RAPv3 (ops)
RAPv4-RAPv3

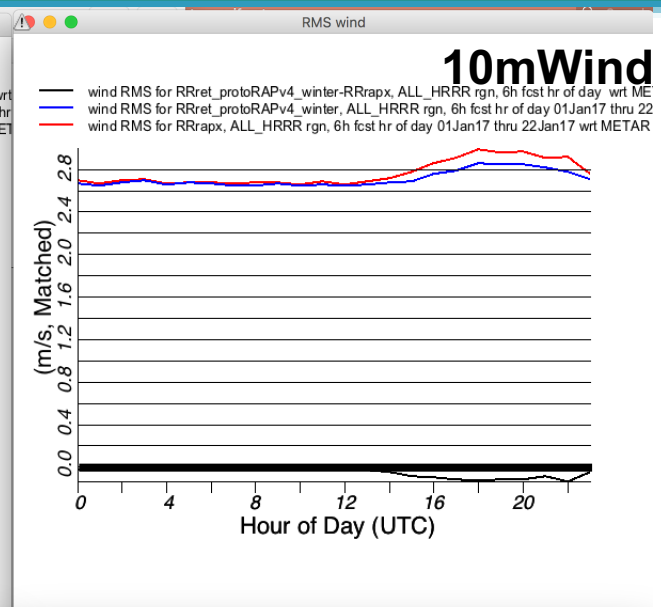
6 hr

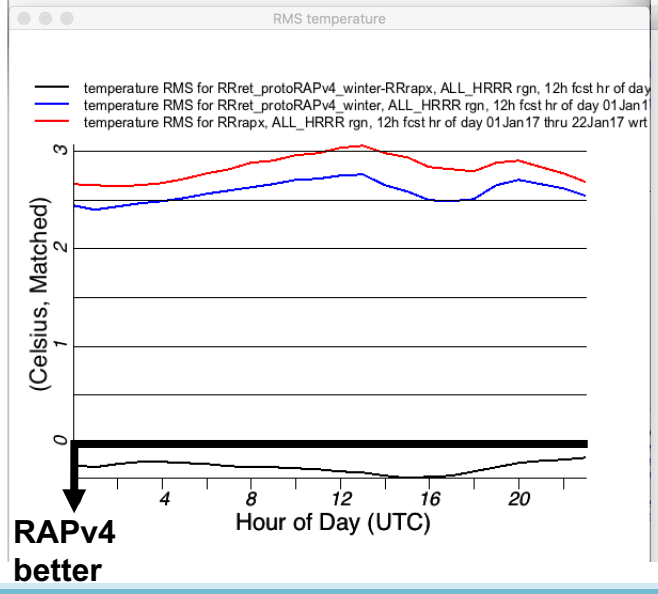
Improved Diurnal T/T_d

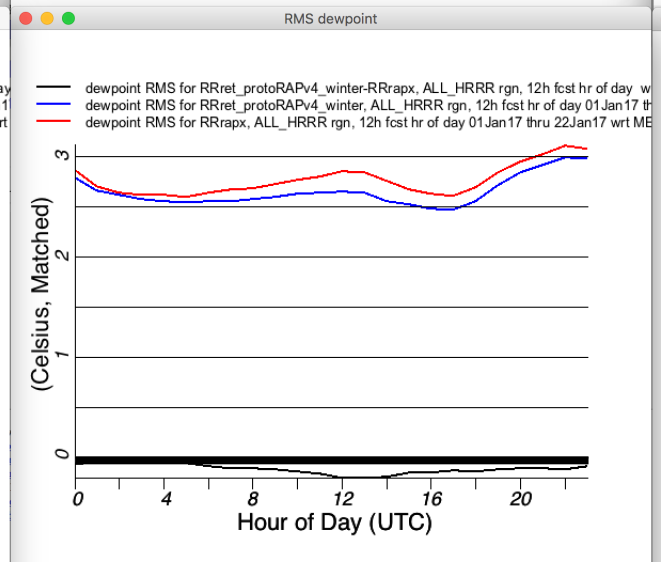
12 hr

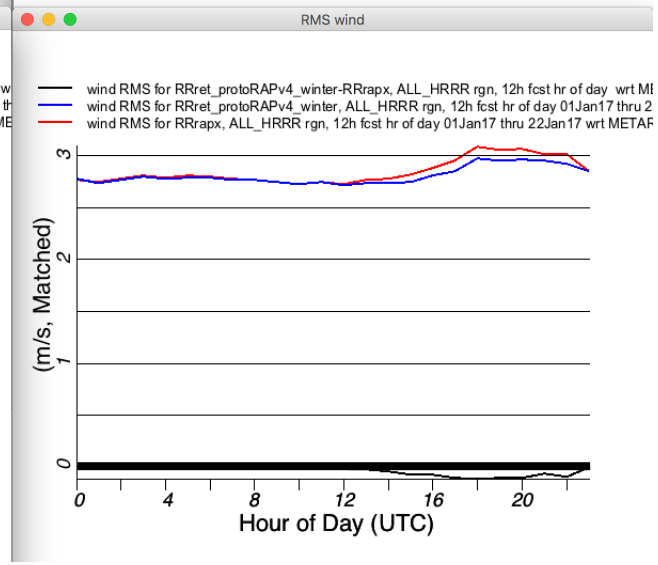










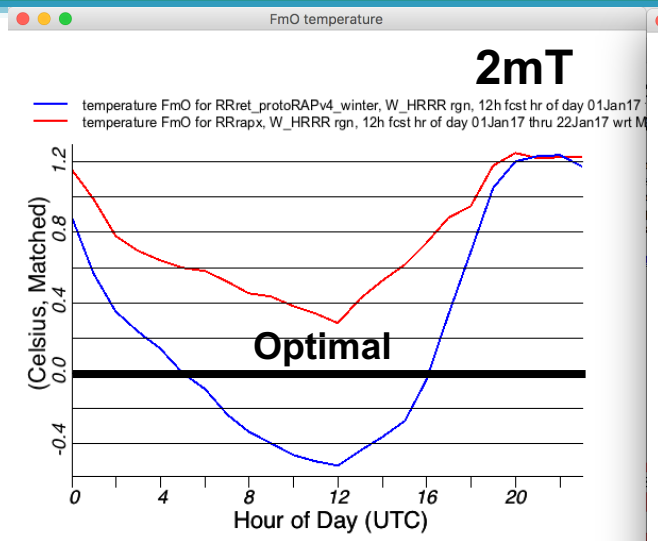


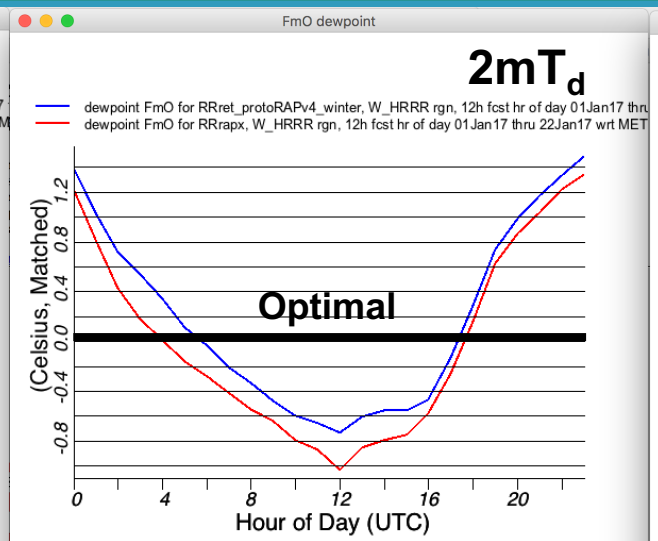
RAP BIAS Surface Winter (Three Weeks Jan 2017)

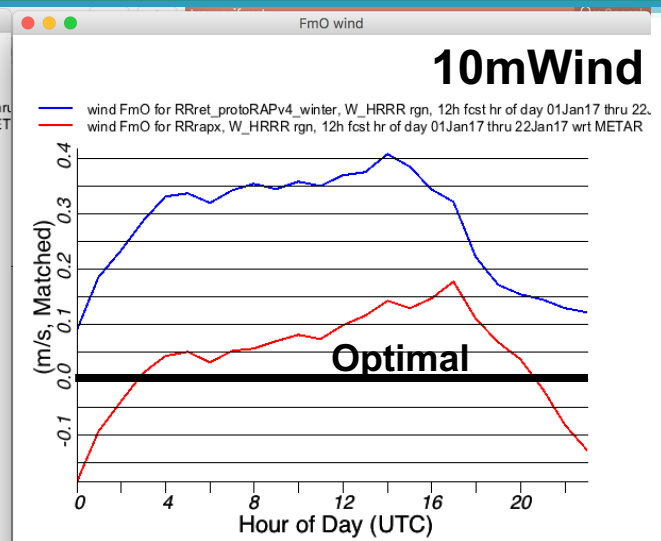
RAPv4
RAPv3 (ops)
12 hr fcsts

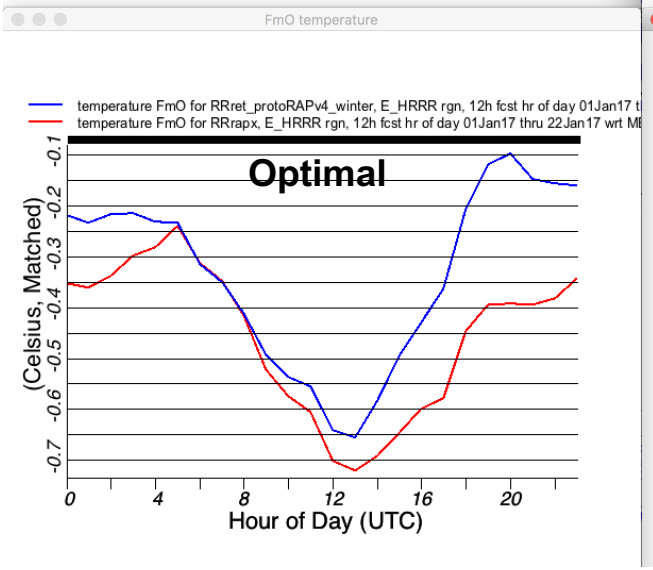
West US

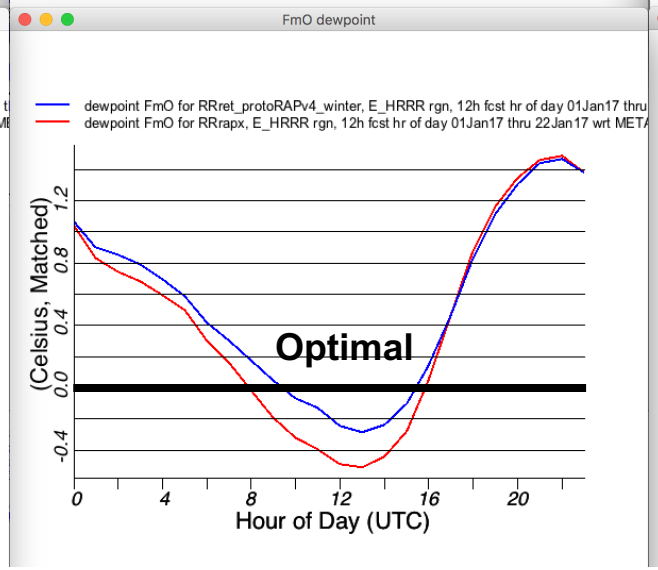
East US

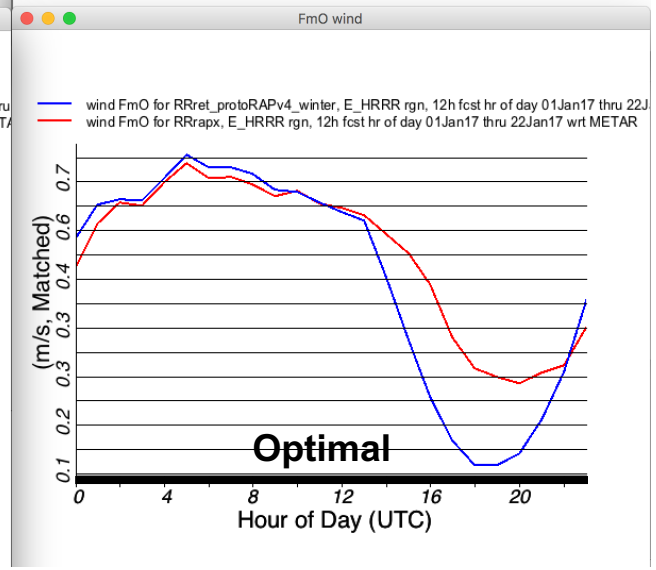












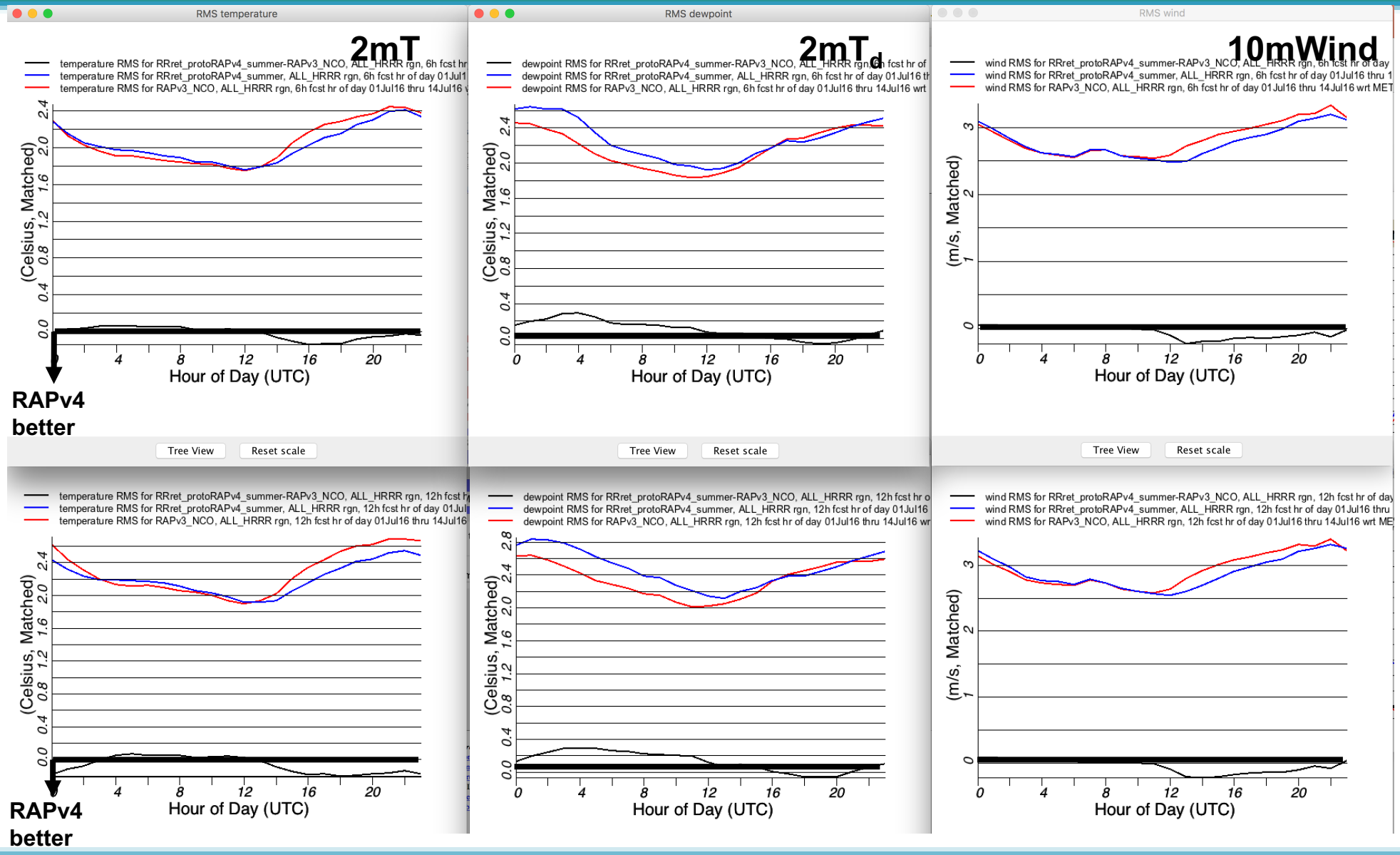
RAP RMSE Surface Summer (Three Weeks Jul 2016)

RAPv4
RAPv3 (ops)
RAPv4-RAPv3

6 hr

Improved Daytime T/T_d/Wind

12 hr

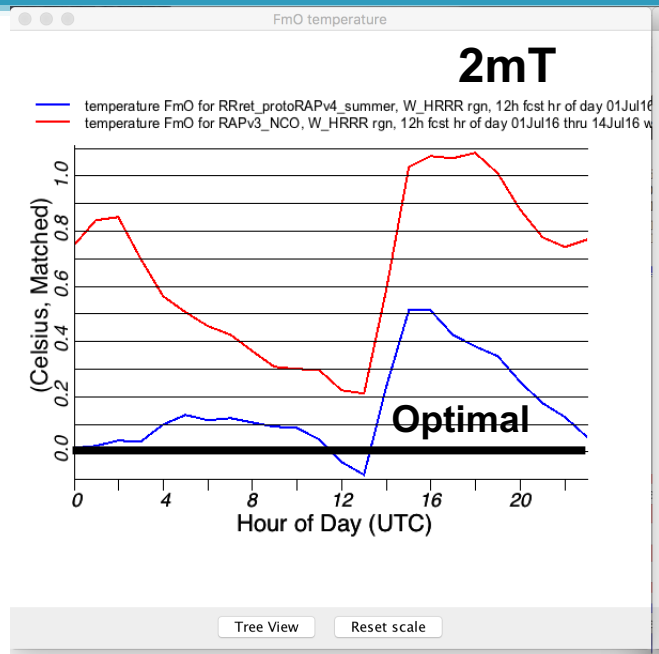


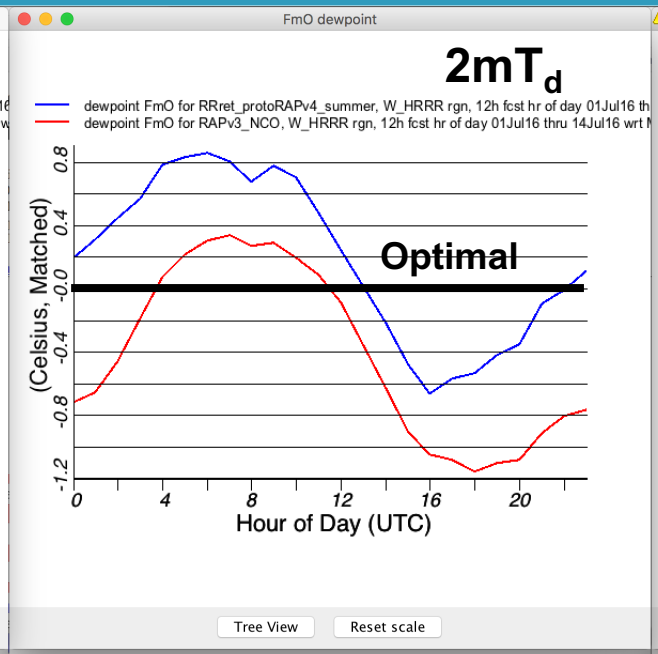
RAP BIAS Surface Summer (Three Weeks Jul 2016)

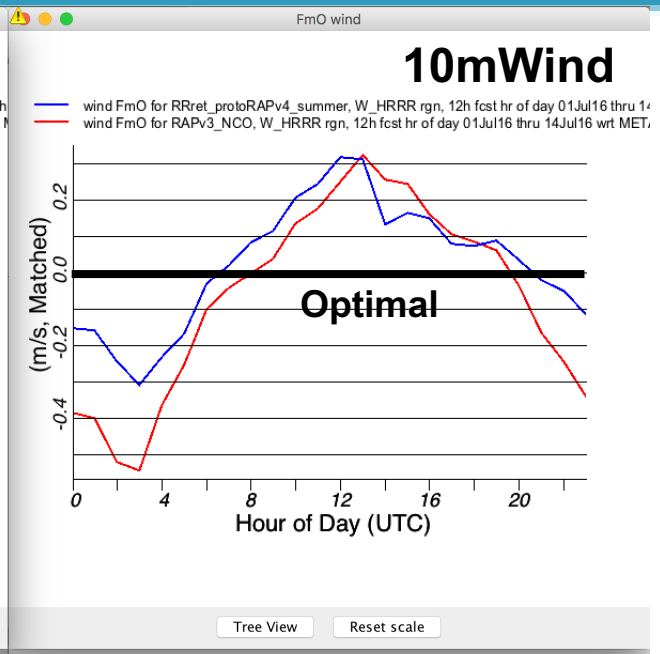
RAPv4
RAPv3 (ops)
12 hr fcsts

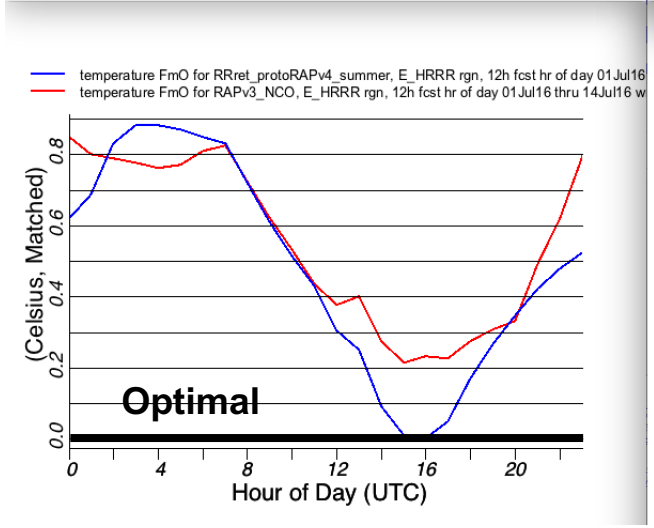
West US

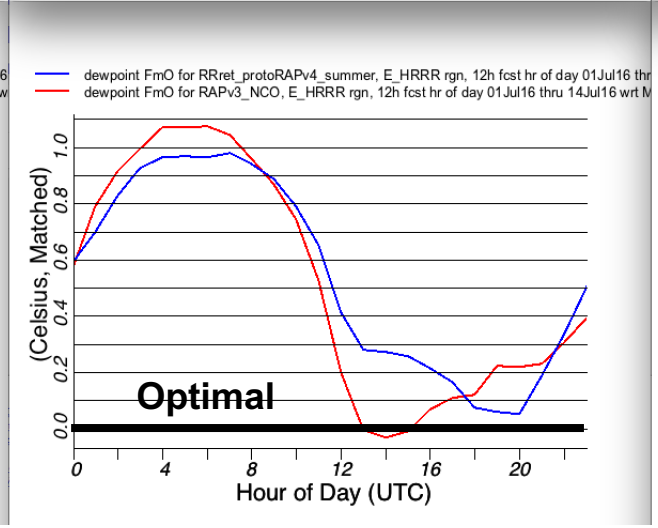
East US

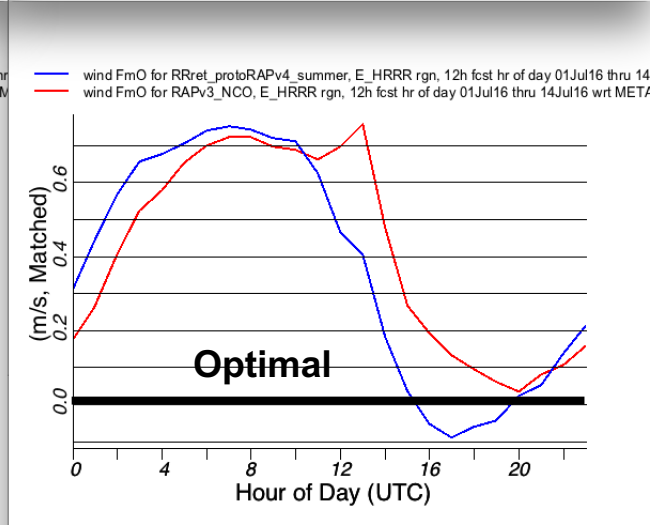






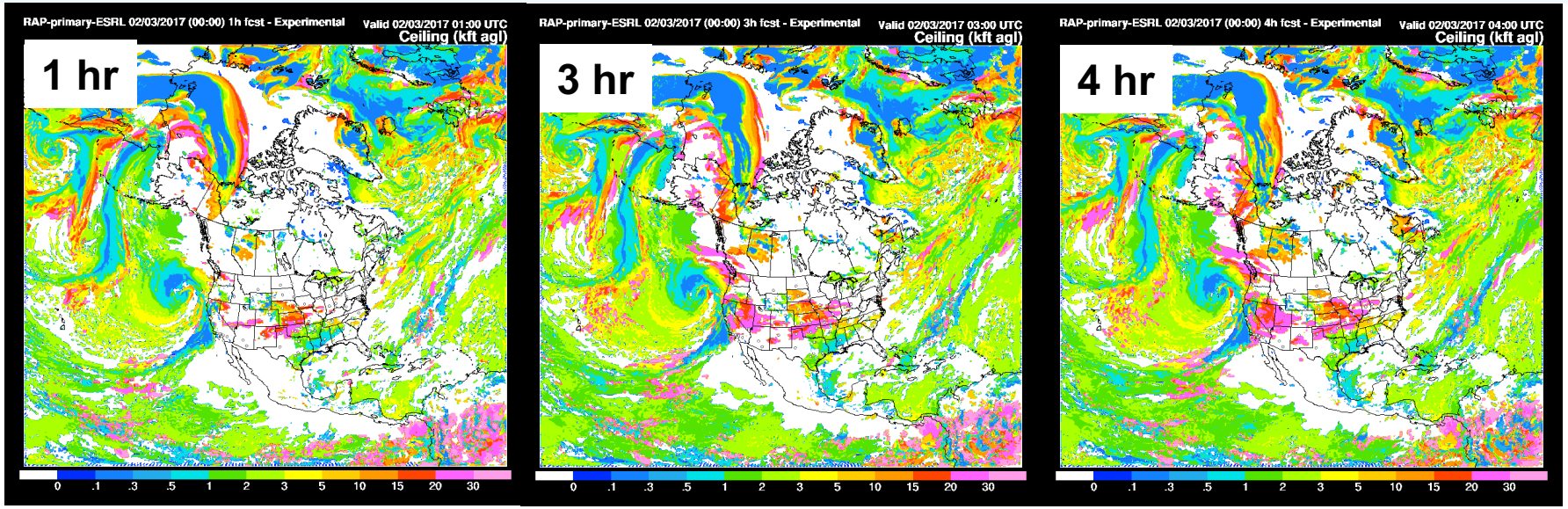




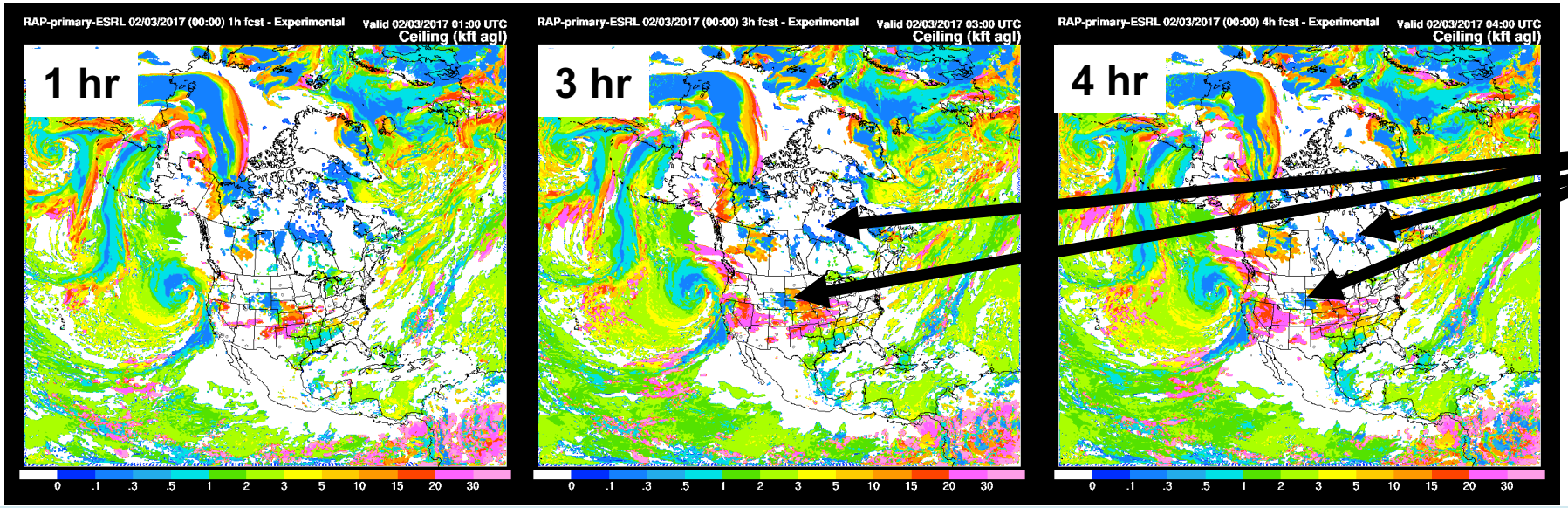


RAP/HRRR Cloud Building w/Smaller Size Distribution

No qnr/qni specified



qnr/qni specified at large values (small sizes)



More low clouds retained

RAP TSS Ceiling Winter (Three Weeks Jan 2017)

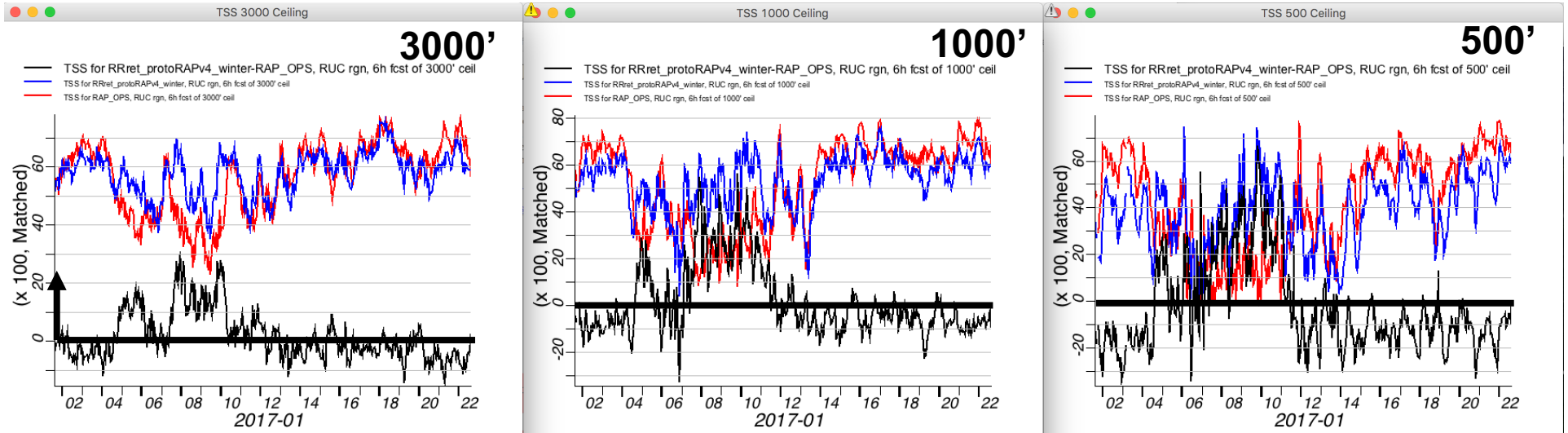
RAPv4
RAPv3 (ops)
RAPv4-RAPv3

6 hr

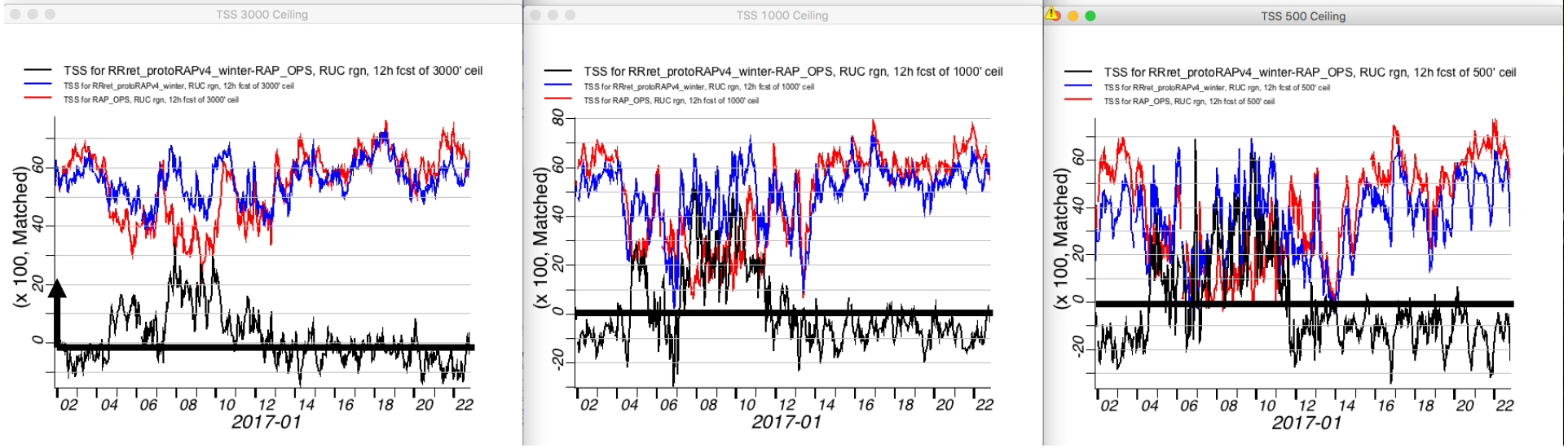
More Skill During Cold/Cloudy Outbreak 6-11 Jan

12 hr

RAPv4 better



RAPv4 better

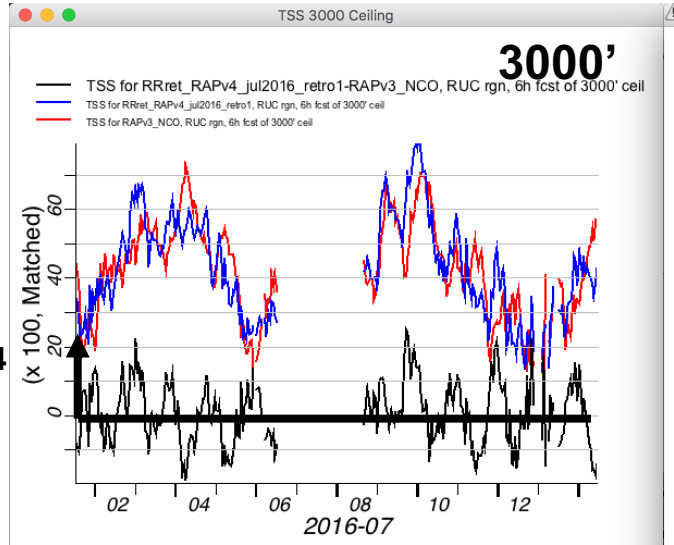


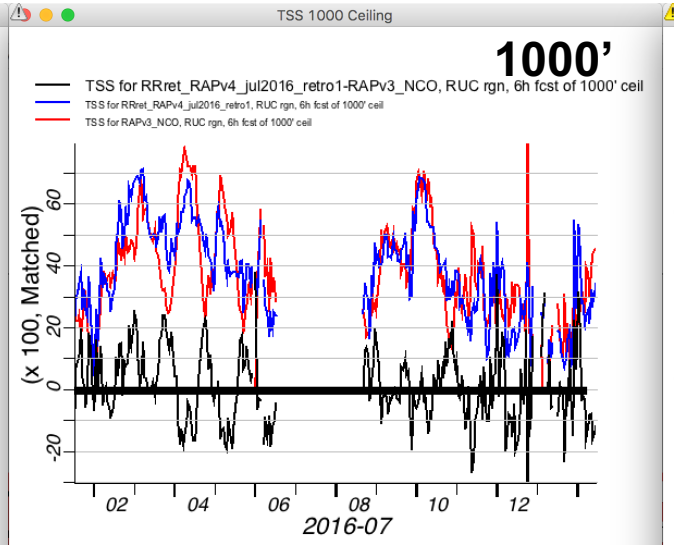
RAP TSS Ceiling Summer (Three Weeks Jul 2016)

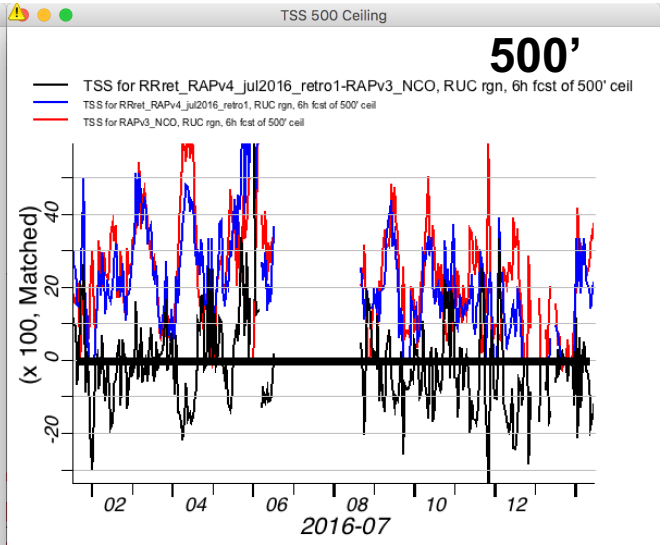
RAPv4
RAPv3 (ops)
RAPv4-RAPv3

6 hr

RAPv4 better

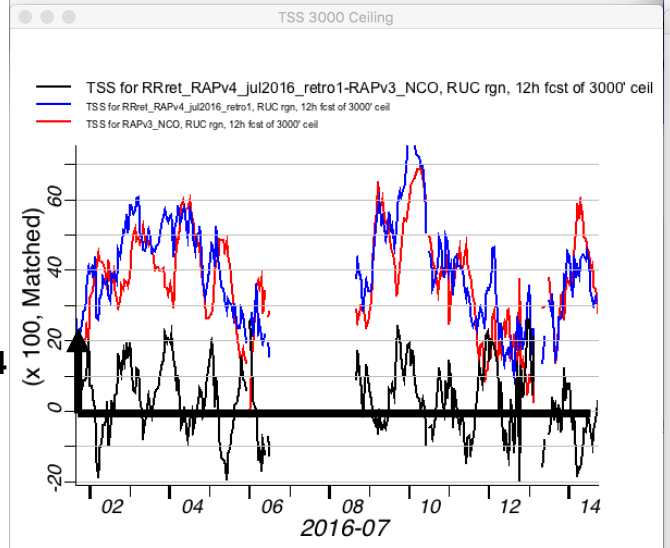


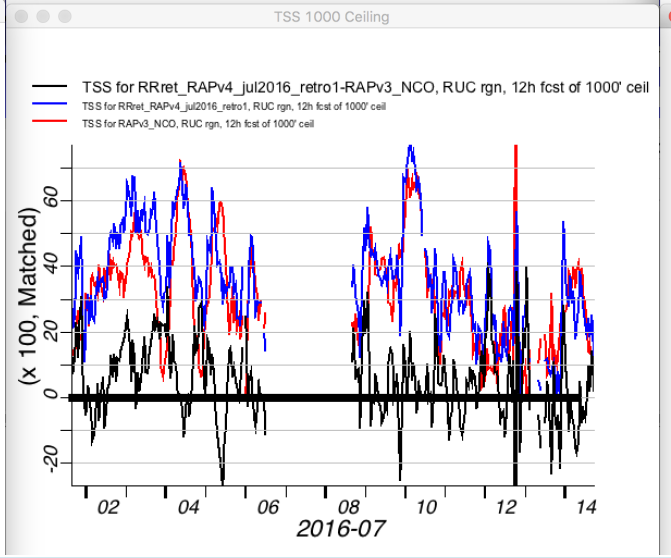


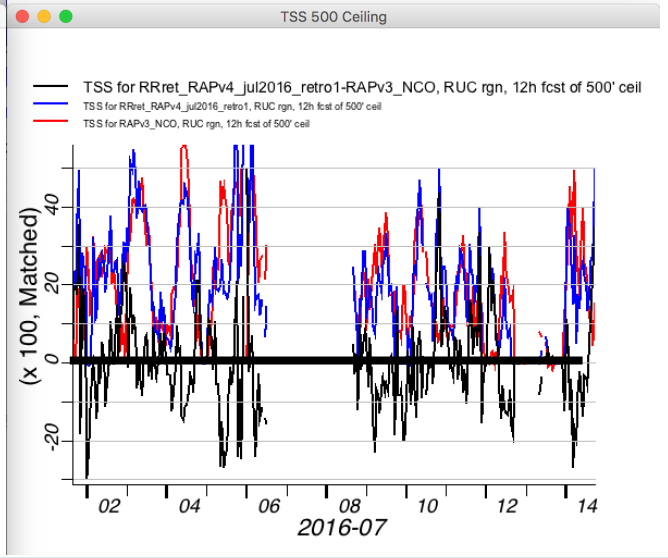


12 hr

RAPv4 better







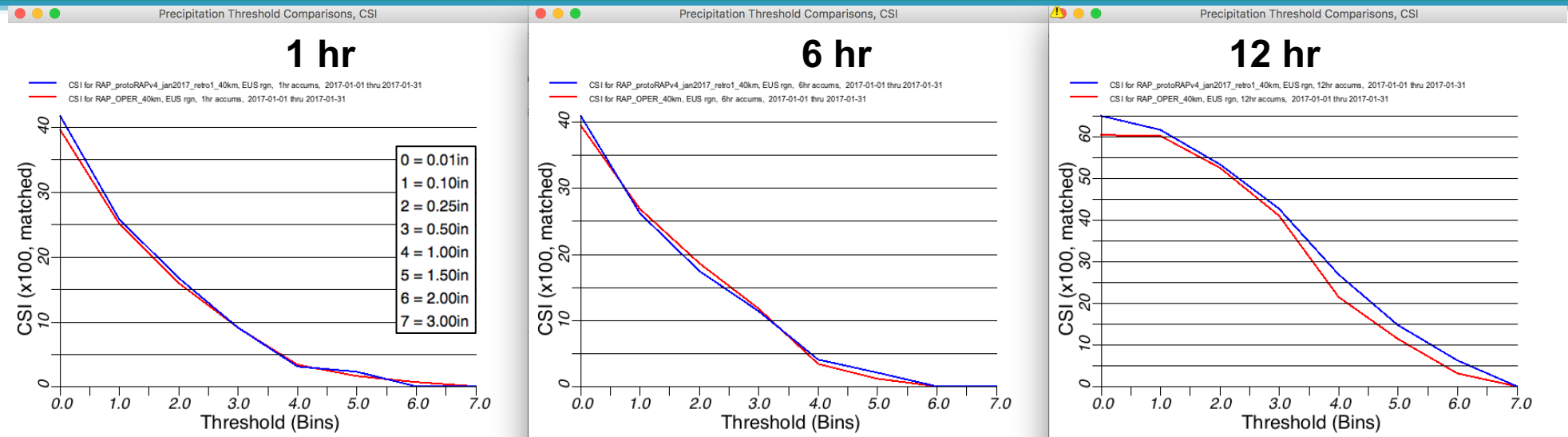
RAP CSI/BIAS Precipitation Winter (Three Weeks Jan 2017)

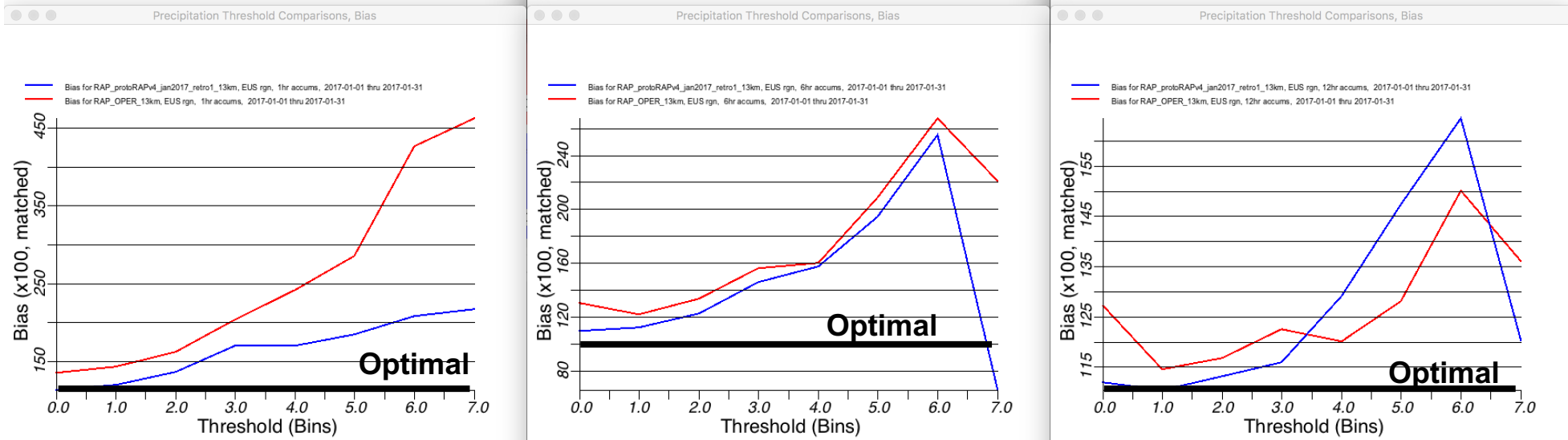
RAPv4
RAPv3 (ops)

CSI
40 km

BIAS
13 km

More Optimal Bias





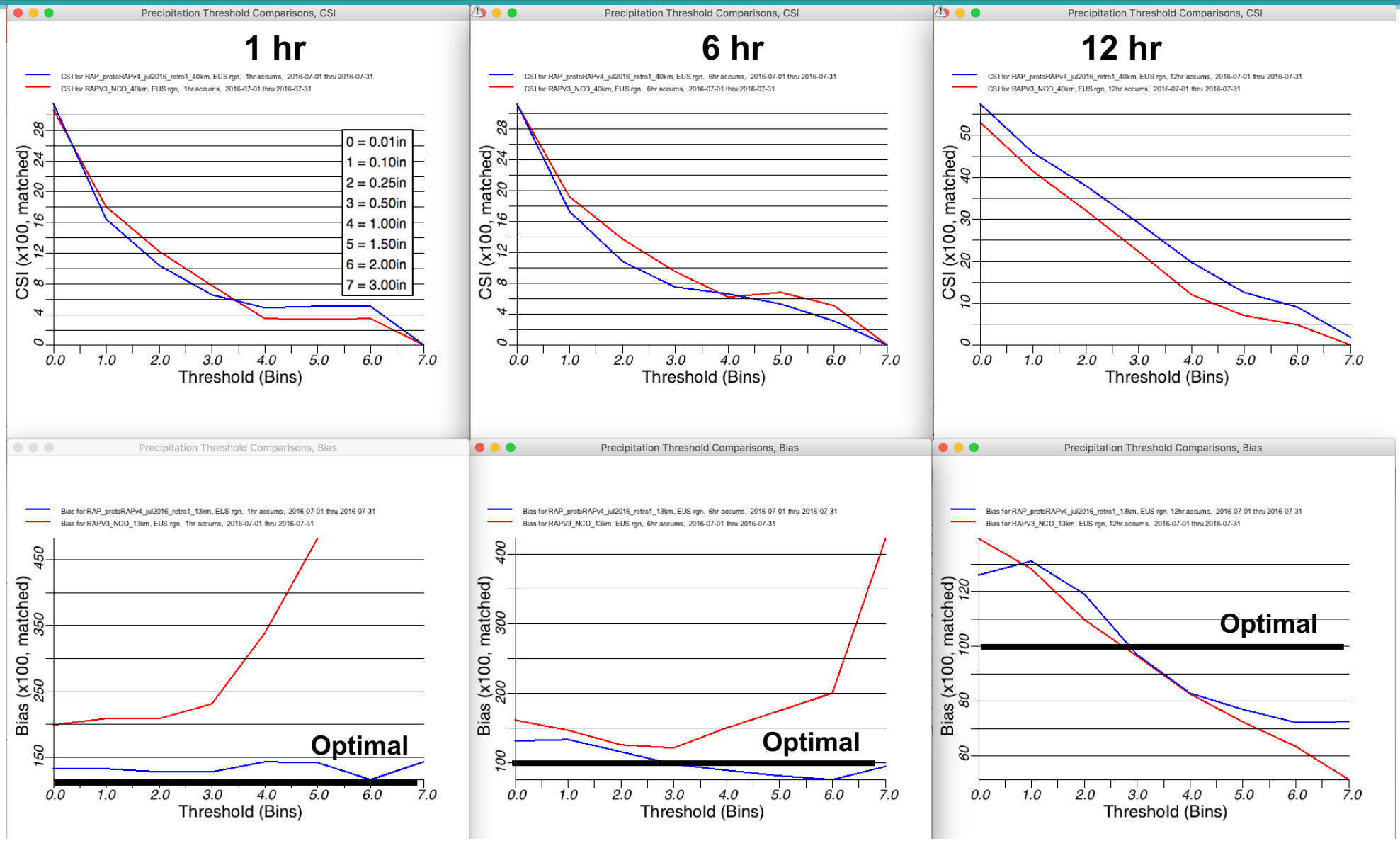
RAP CSI/BIAS Precipitation Summer (Three Weeks Jul 2016)

RAPv4
RAPv3 (ops)

CSI
40 km

BIAS
13 km

More Optimal Bias



RAP/HRRR: Hourly-Updating Weather Forecast Suite

13-km Rapid Refresh (RAPv4) – to 39h (Feb 2018)

Initial & Lateral Boundary Conditions

3-km High-Resolution Rapid Refresh (HRRRv3) – to 36h (Feb 2018)

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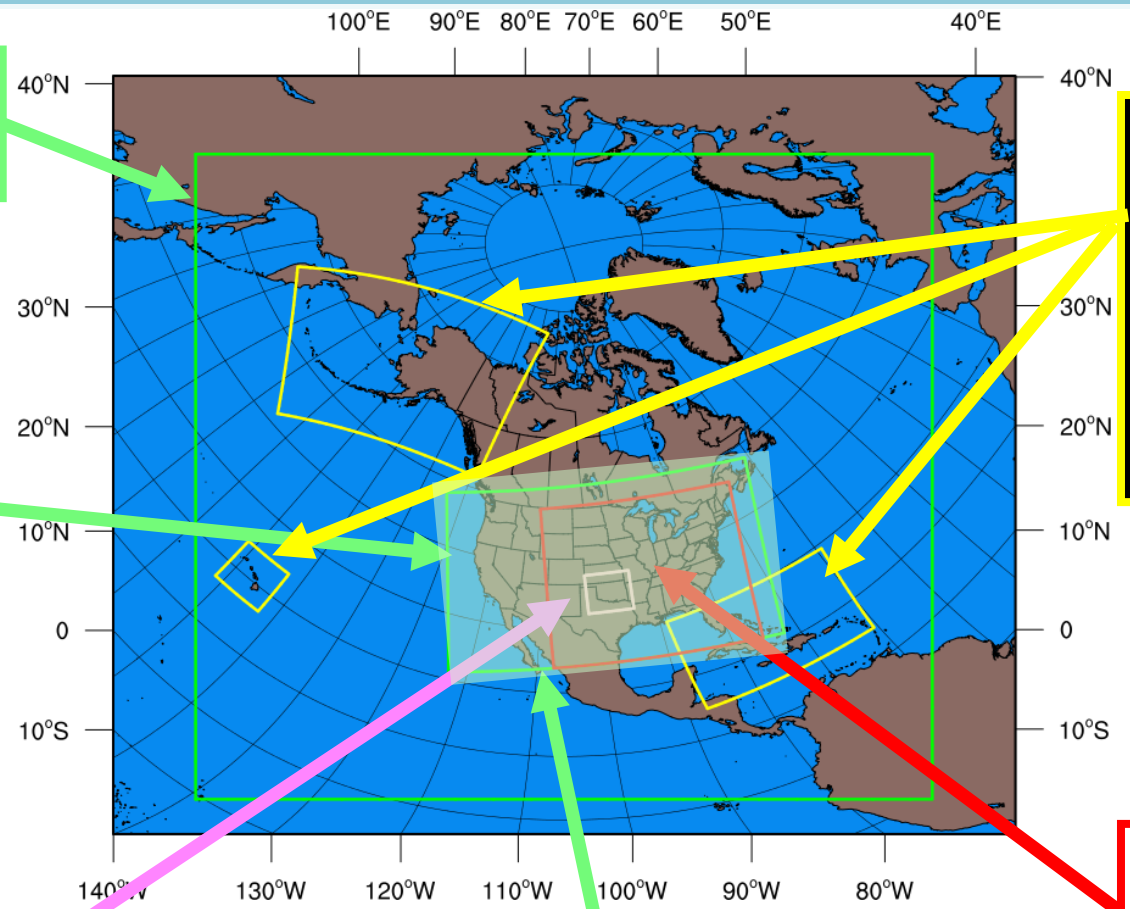
750-m HRRR nest Scale-ware Physics Testing (ongoing)



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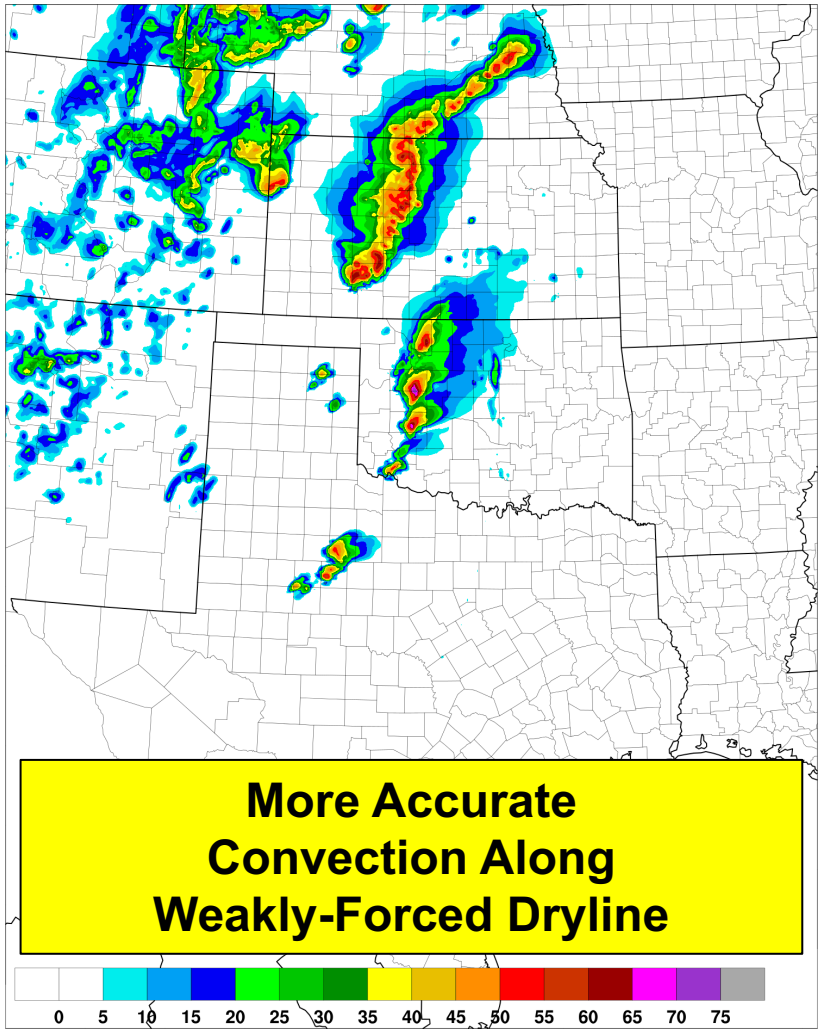
3-km HRRR-Smoke (VIIRS fire data)

3-km Storm-Scale Ensemble Analysis and Forecast (HRRRE) 55% CONUS HRRR Experimental (ongoing)

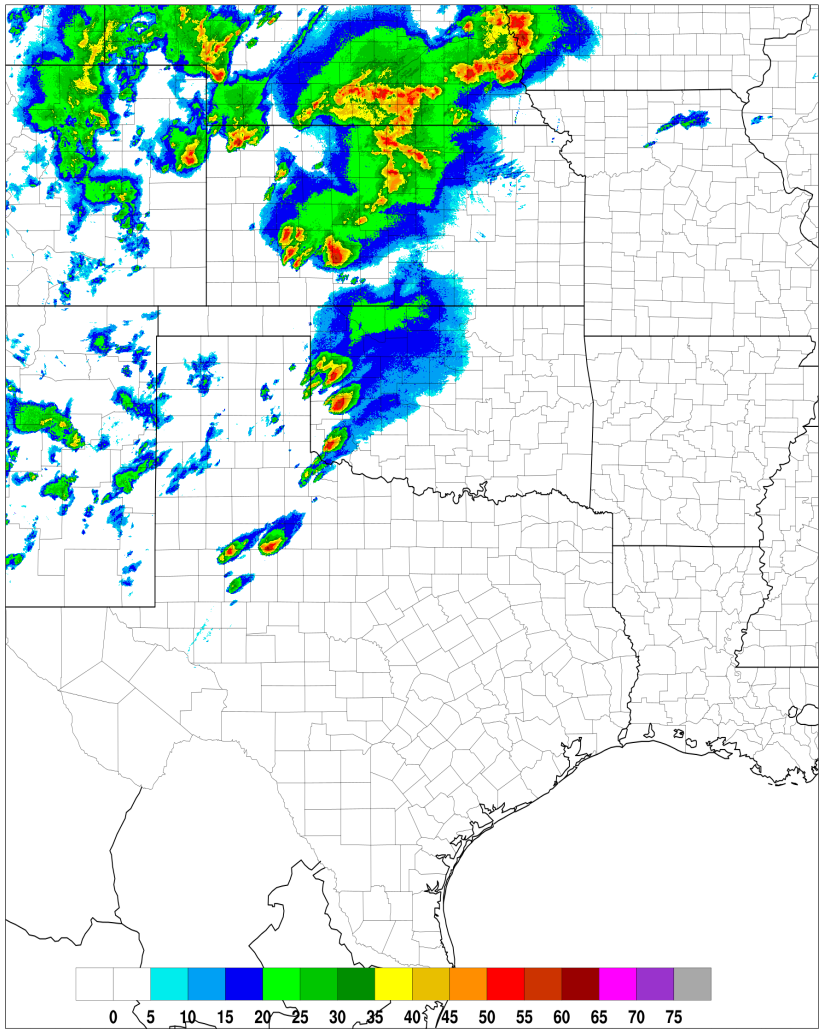
HRRR Improved Convective Forecasts

Experimental HRRRv3 13 hr fcst
Valid 00 UTC 17 May 2017

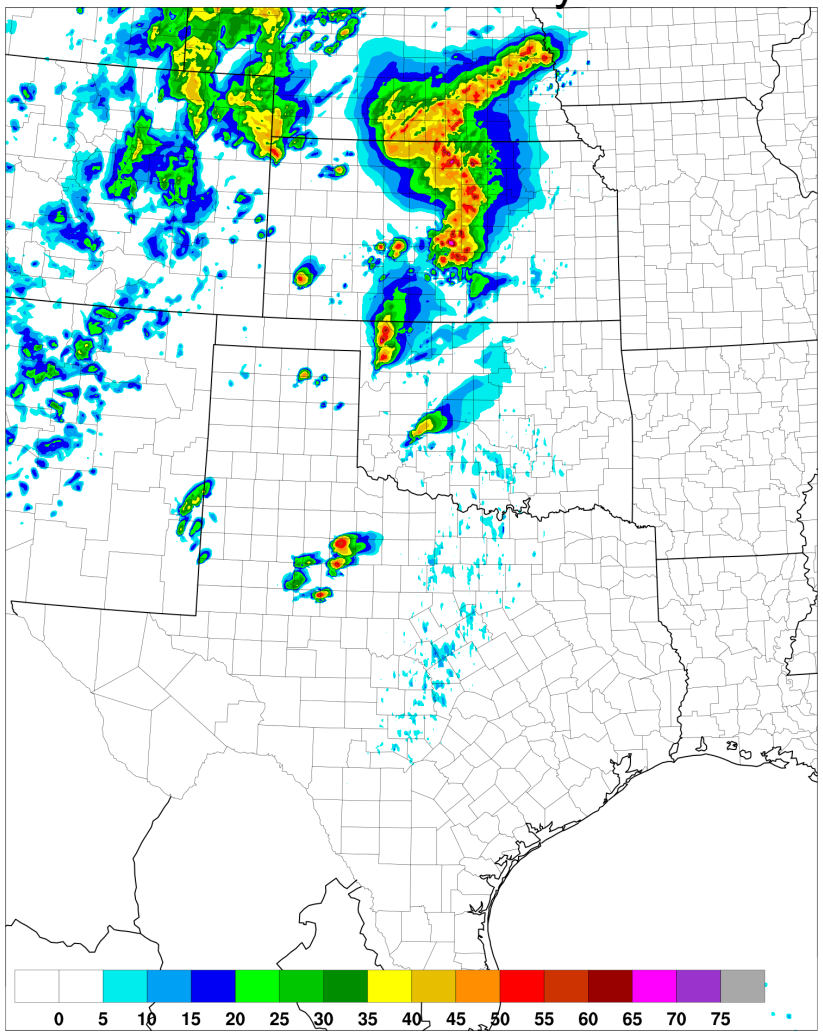


More Accurate Convection Along Weakly-Forced Dryline

Composite Reflectivity Observations
00 UTC 17 May 2017



Operational HRRRv2 13 hr fcst
Valid 00 UTC 17 May 2017



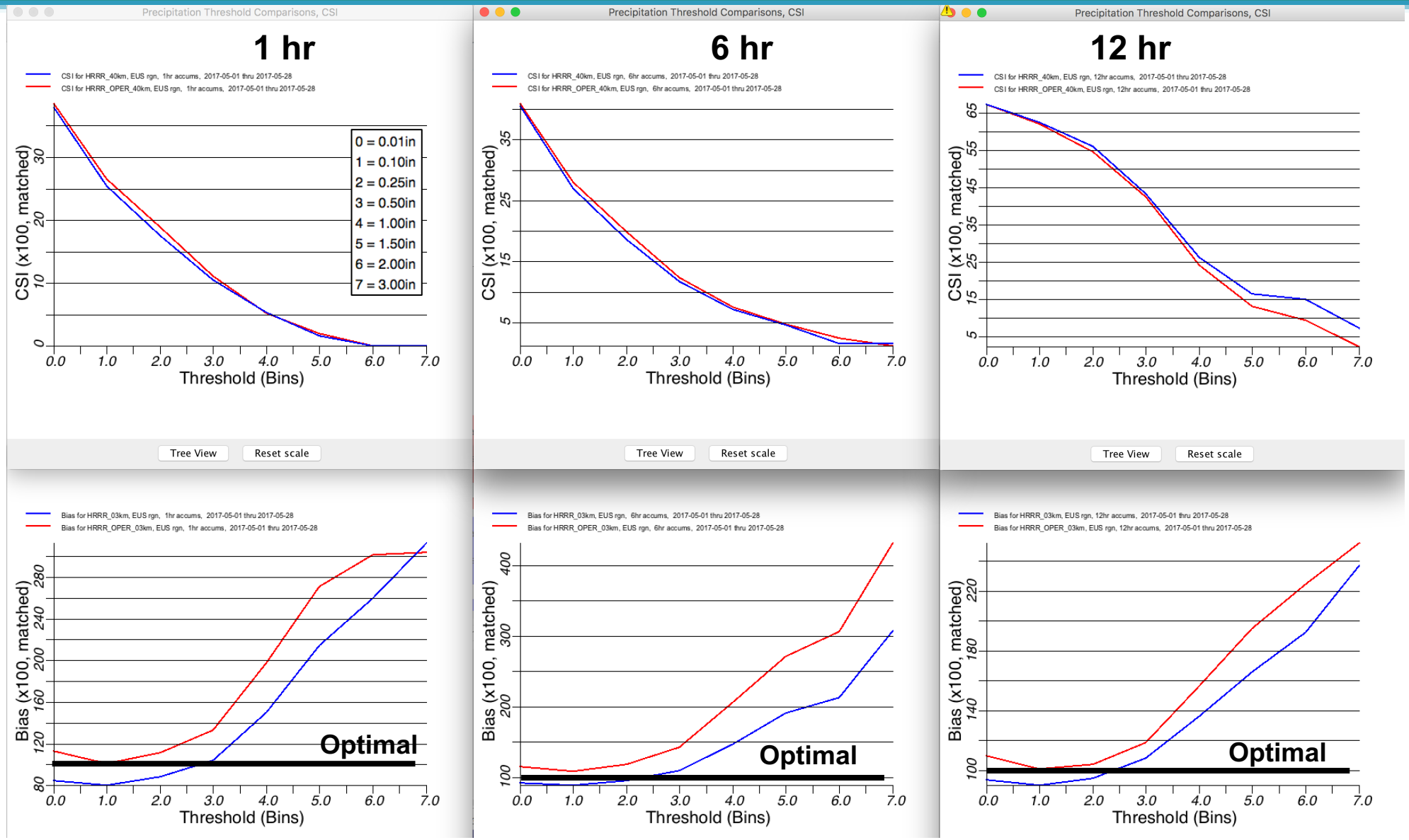
HRRR CSI/BIAS Precipitation Spring (Three Weeks May 2017)

HRRRv3
HRRRv2 (ops)

CSI
40 km

BIAS
3 km

More Optimal Bias



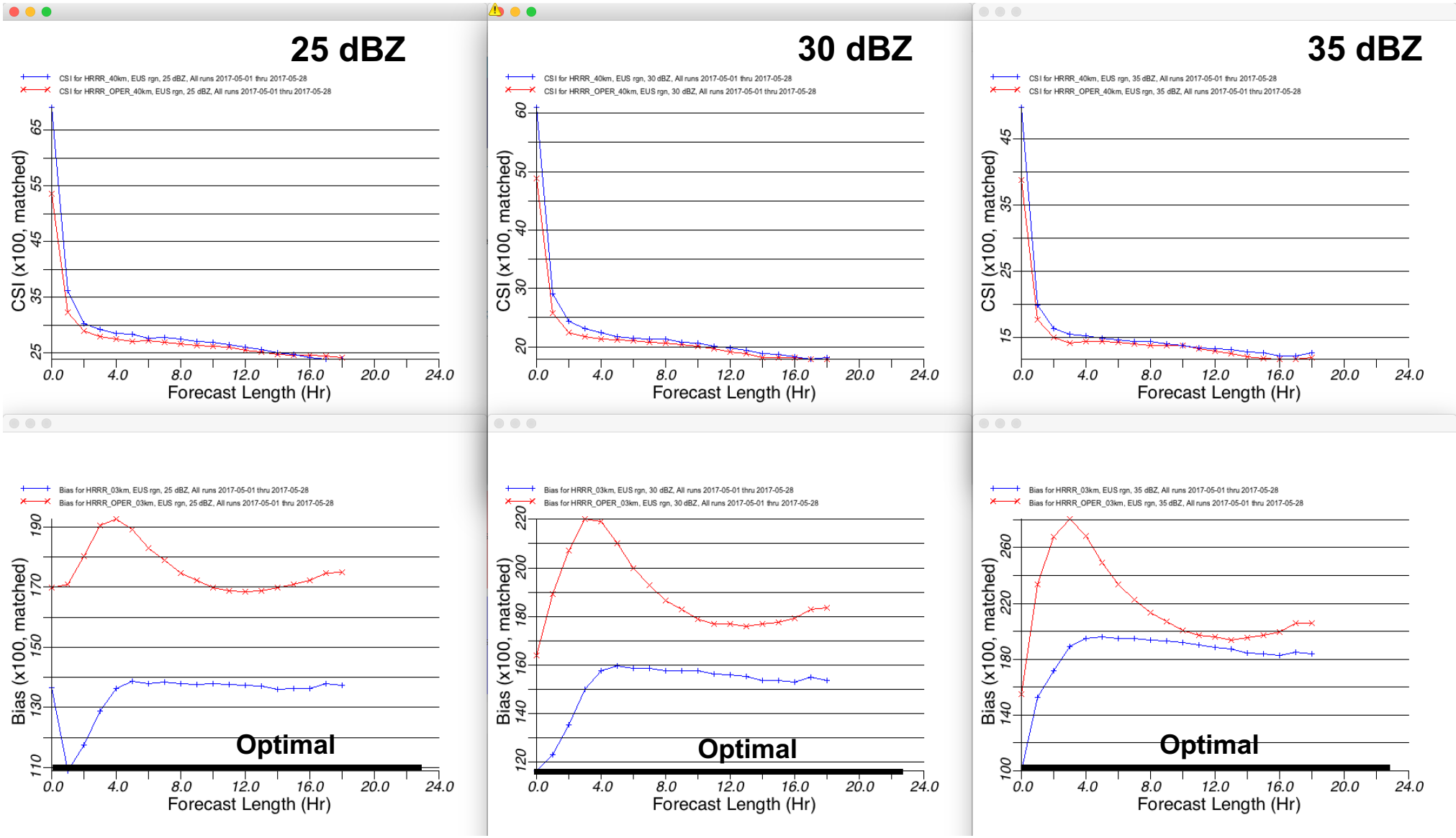
HRRR CSI/BIAS Reflectivity Spring (Three Weeks May 2017)

HRRRv3
HRRRv2 (ops)

CSI
40 km

BIAS
3 km

More Optimal Bias



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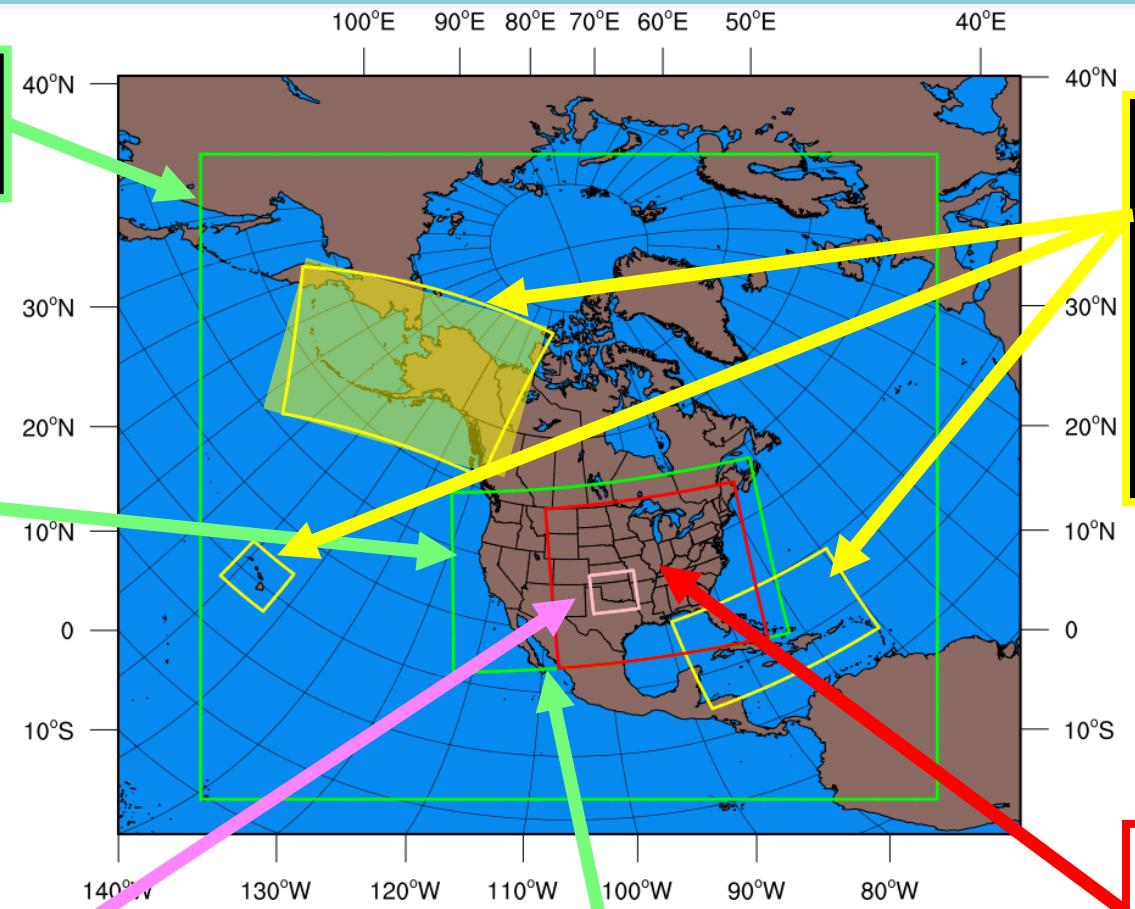

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3-km High-Resolution Time Lagged Ensemble (HRRR-TLE)

3-km HRRR-Smoke (VIIRS fire data)

3-km Storm-Scale Ensemble Analysis and Forecast (HRRRE) 55% CONUS HRRR Experimental (ongoing)

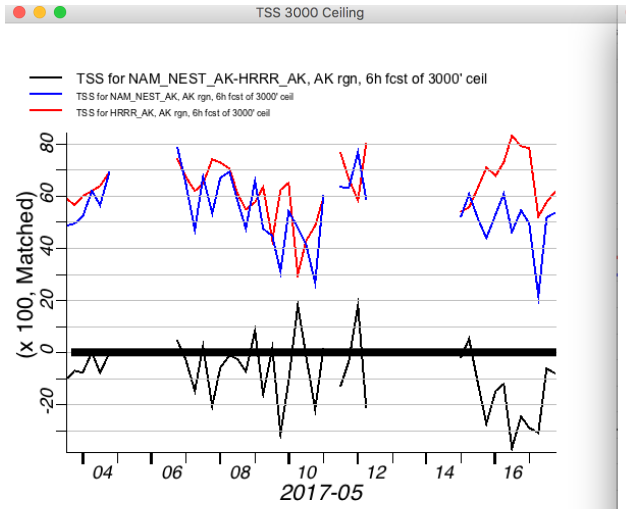
Ceiling (True Skill Score) HRRR-AK vs NAM-NEST-AK (two weeks)

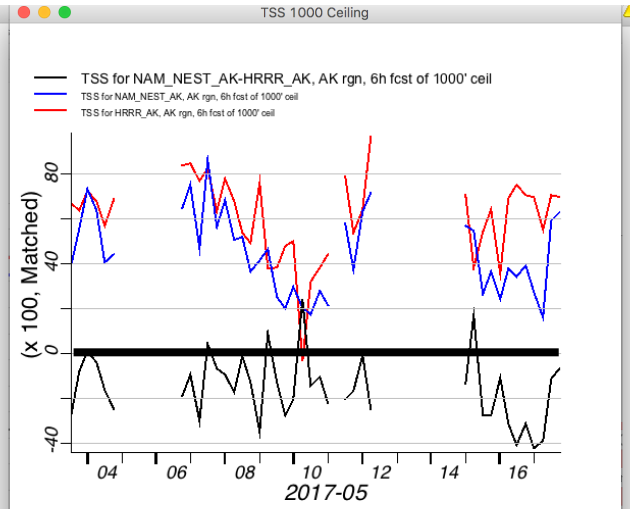
NAM-AK
HRRR-AK
NAM-HRRR

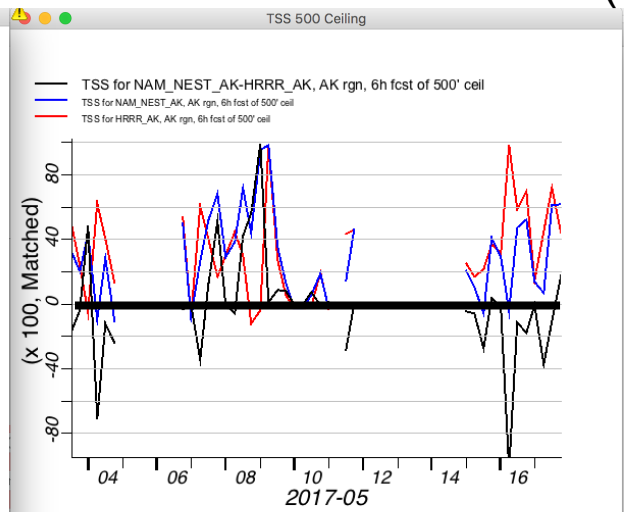
3000’ 1000’ 500’ (rare)

6 hr

HRRR better

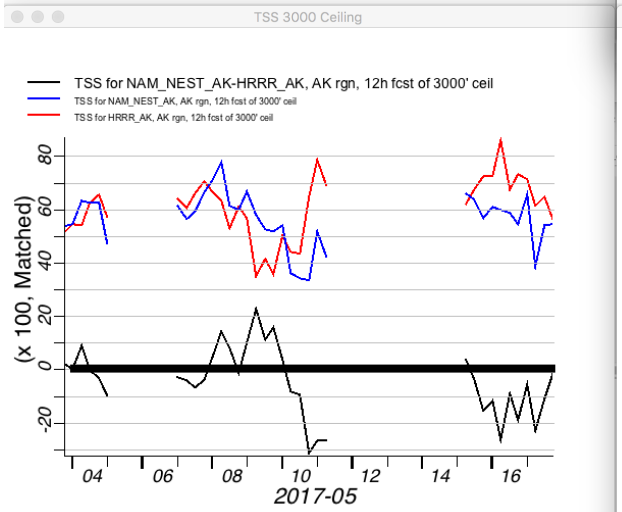


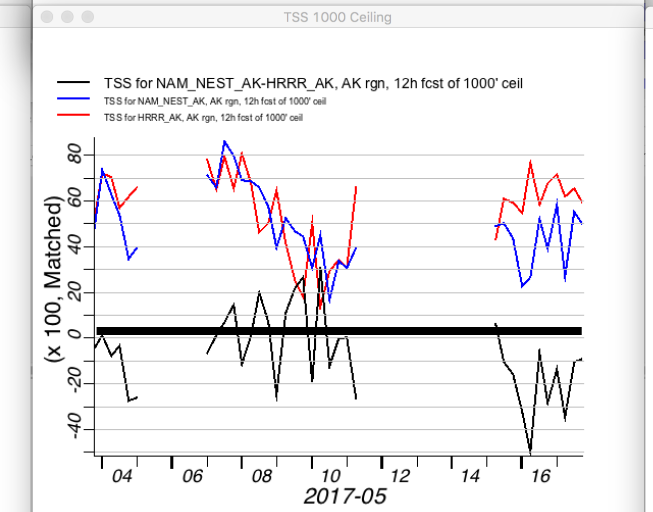


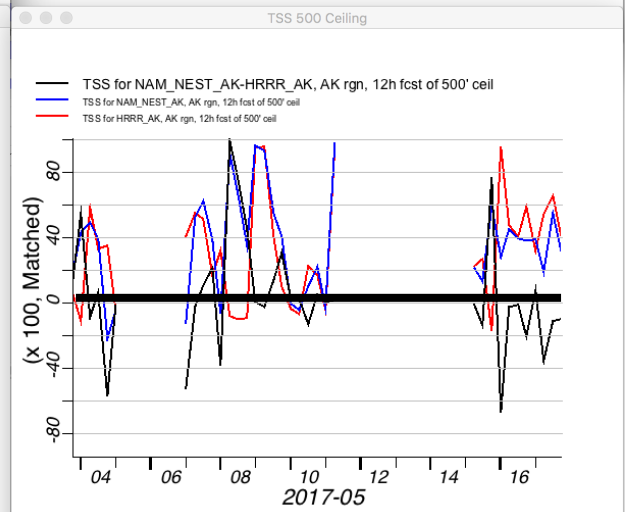


12 hr

HRRR better







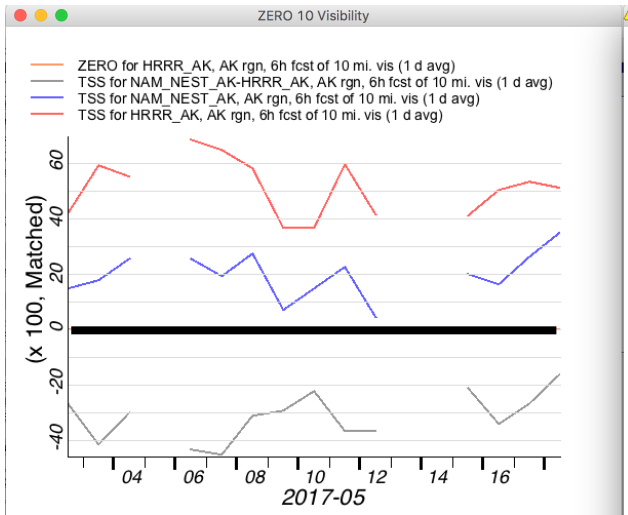
Visibility (True Skill Score) HRRR-AK vs NAM-NEST-AK (two weeks)

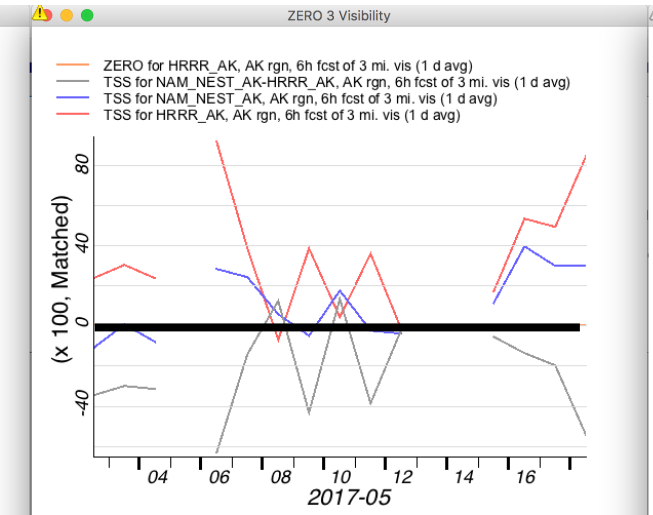
NAM-AK
HRRR-AK
NAM-HRRR

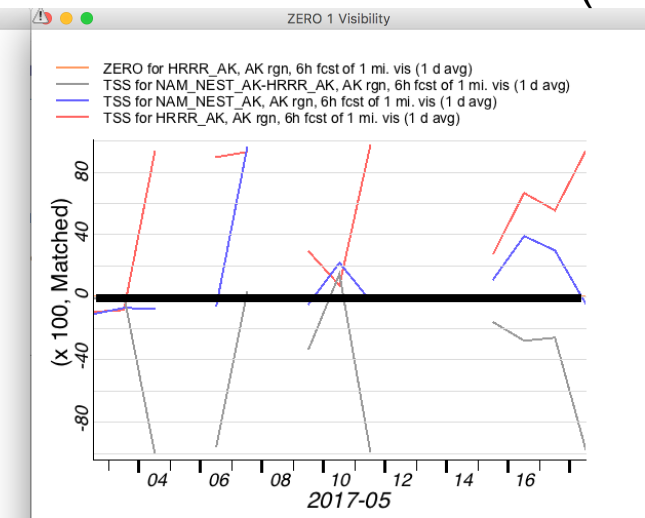
10 mi | 3 mi | 1 mi (rare)

6 hr

HRRR better

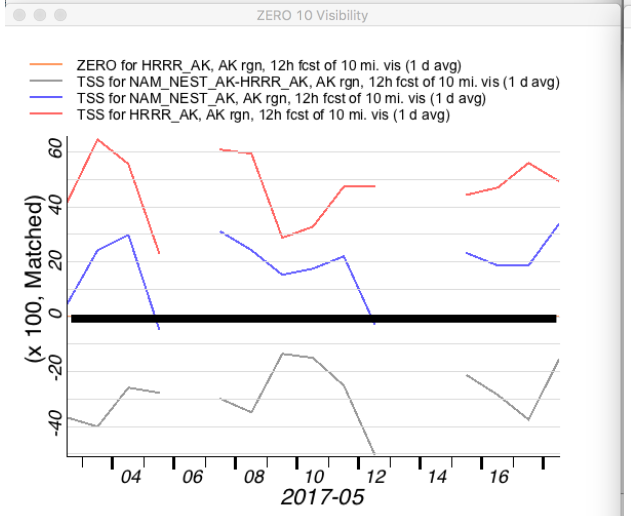


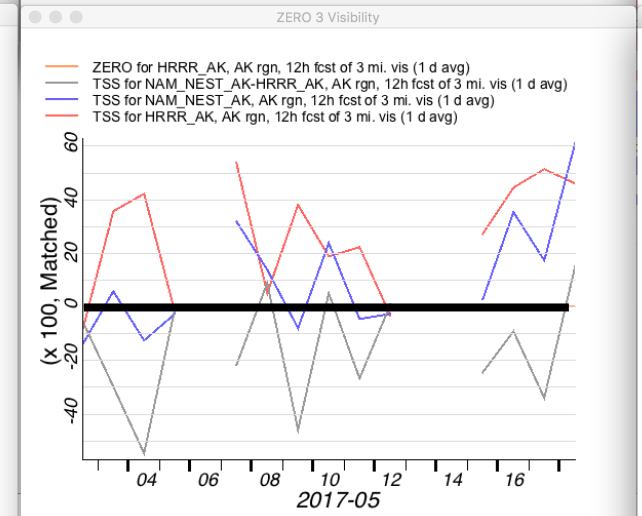


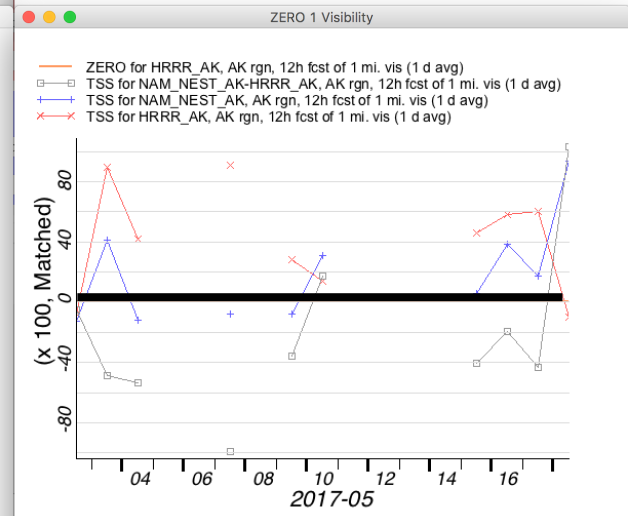


12 hr

HRRR better







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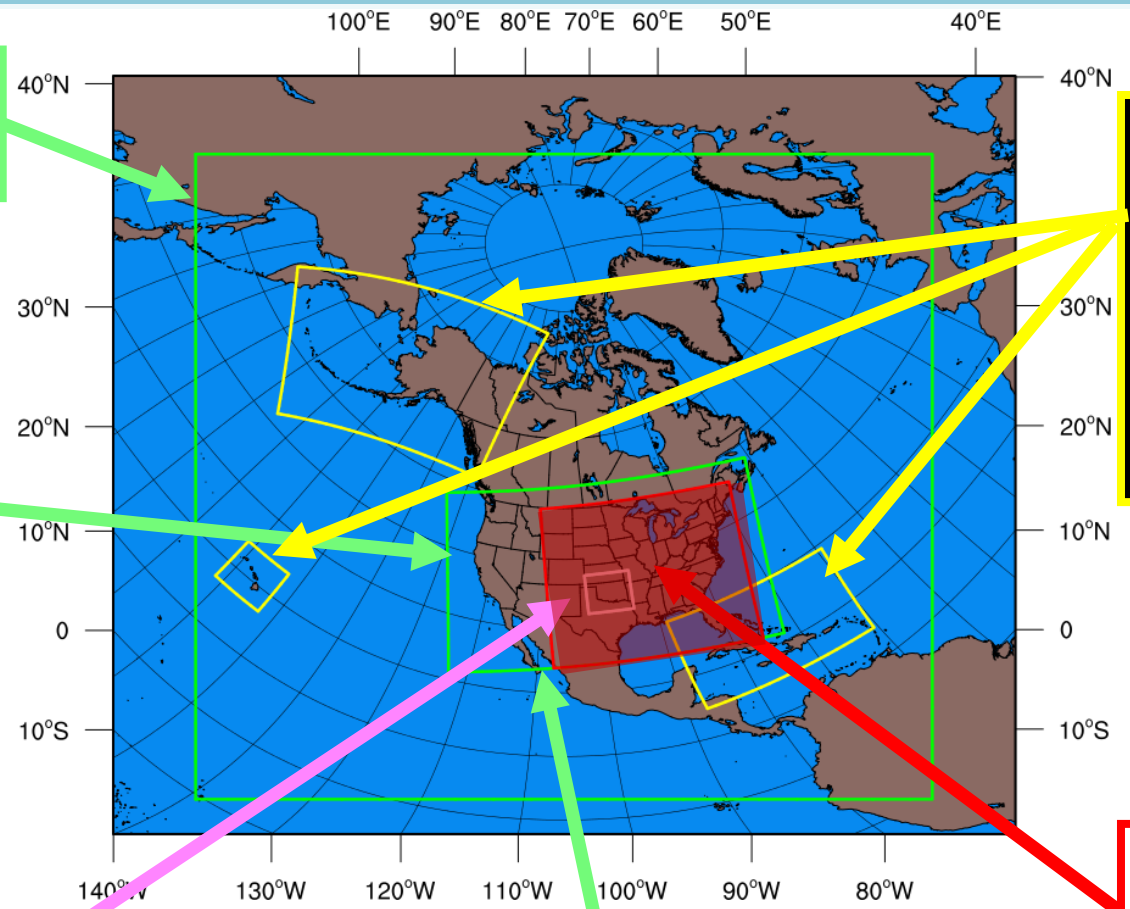
750-m HRRR nest Scale-ware Physics Testing (ongoing)



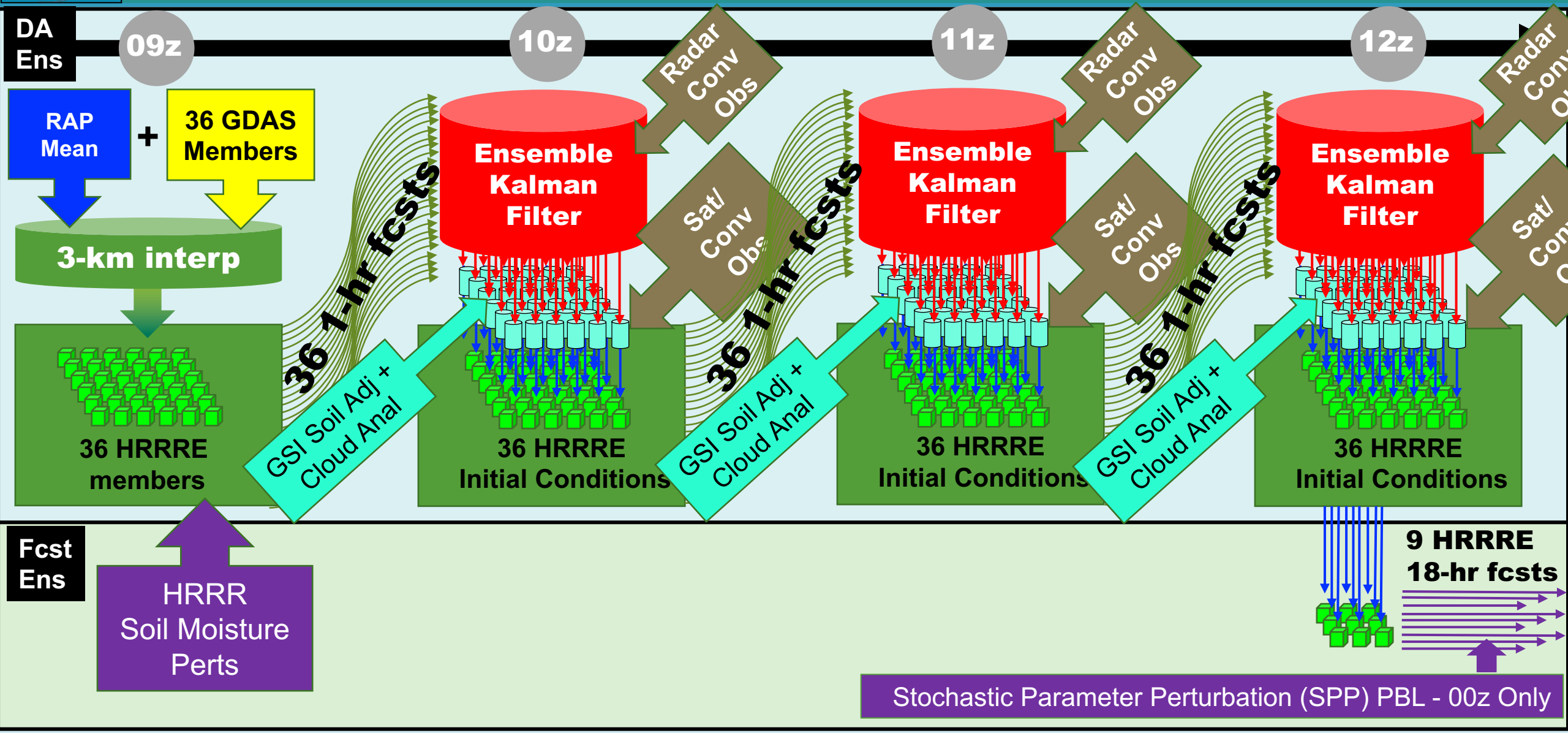
3-km High-Resolution Rapid Refresh Alaska, Hawaii and Puerto Rico Testing (HRRR-AK, HRRR-HI, HRRR-PR) Experimental (ongoing)

3-km High-Resolution Time Lagged Ensemble (HRRR-TLE)

3-km HRRR-Smoke (VIIRS fire data)

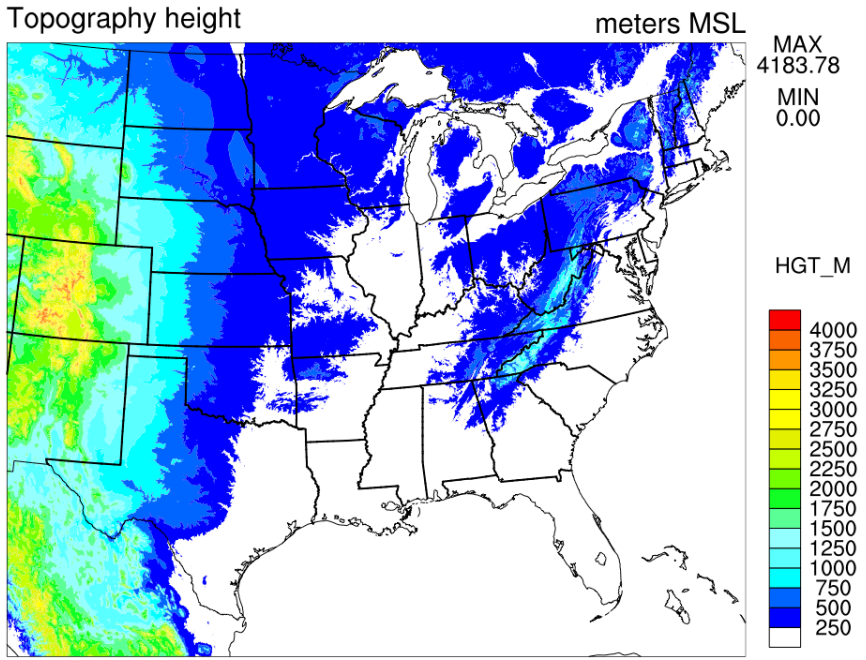
3-km Storm-Scale Ensemble Analysis and Forecast (HRRRE) 55% CONUS HRRR Experimental (ongoing)

HRRRE 2017 Design



HRRRE 2017 (01 March – 30 June 2017)

55% CONUS HRRR



Proof-of-concept
Real-time demonstration
With NSSL Experimental
WoF System for ensembles
"NEWS-e"

Real-Time Web Graphics

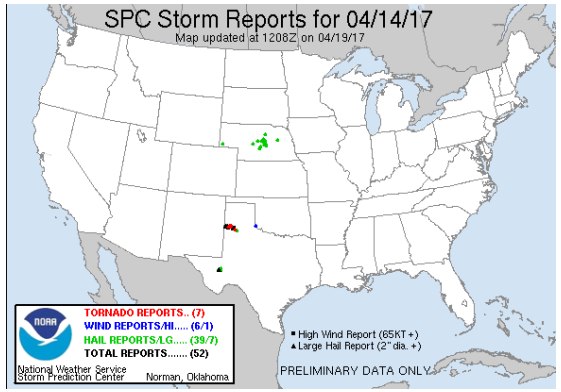
https://rapidrefresh.noaa.gov/hrrr/HRRRE

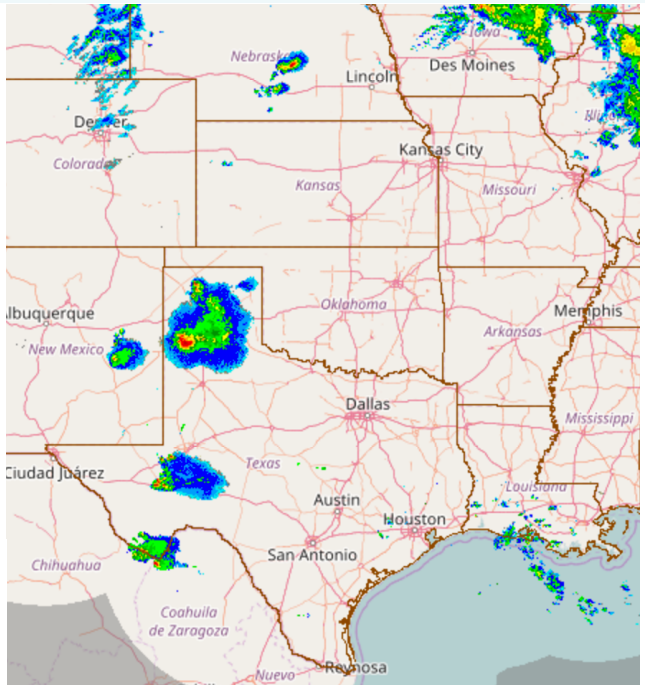
- Single core (ARW)
- Ensemble DA (DART and GSI-EnKF)
- RAP mean + GDAS perturbations w/more inflation
- Conventional observations
- Radar reflectivity observations
- Stochastic physics
- Cloud analysis
- Soil adjustments
- HRRR-TLE post-processing

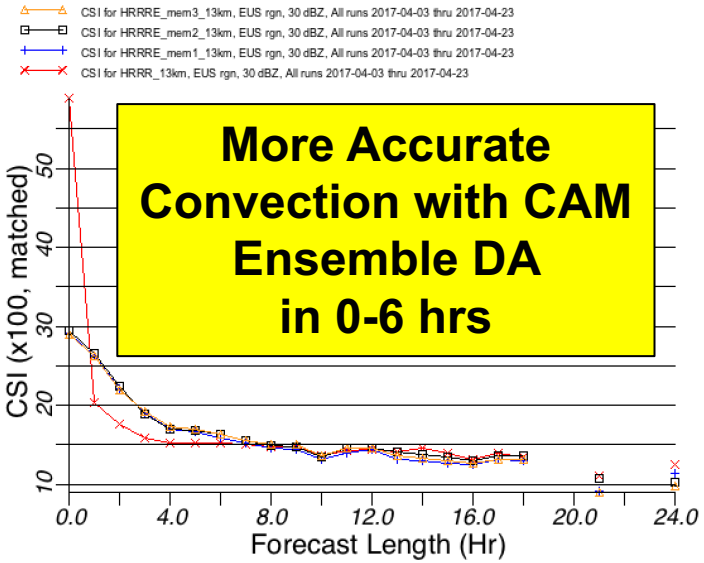
Assimilation	Forecast
36 members	12z – Nine members to 18 hrs
1 hr cycling	15z – Nine members to 18 hrs
15 fcsts / day	18z – Nine members to 18 hrs
Start 09z day one	21z – Nine members to 18 hrs
End 00z day two	00z – Nine members to 36 hrs

Ensemble Forecast Challenge: Spread vs Error

Isolated Supercell
00z 15 April 2017

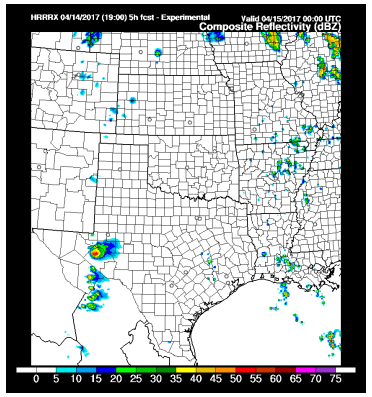


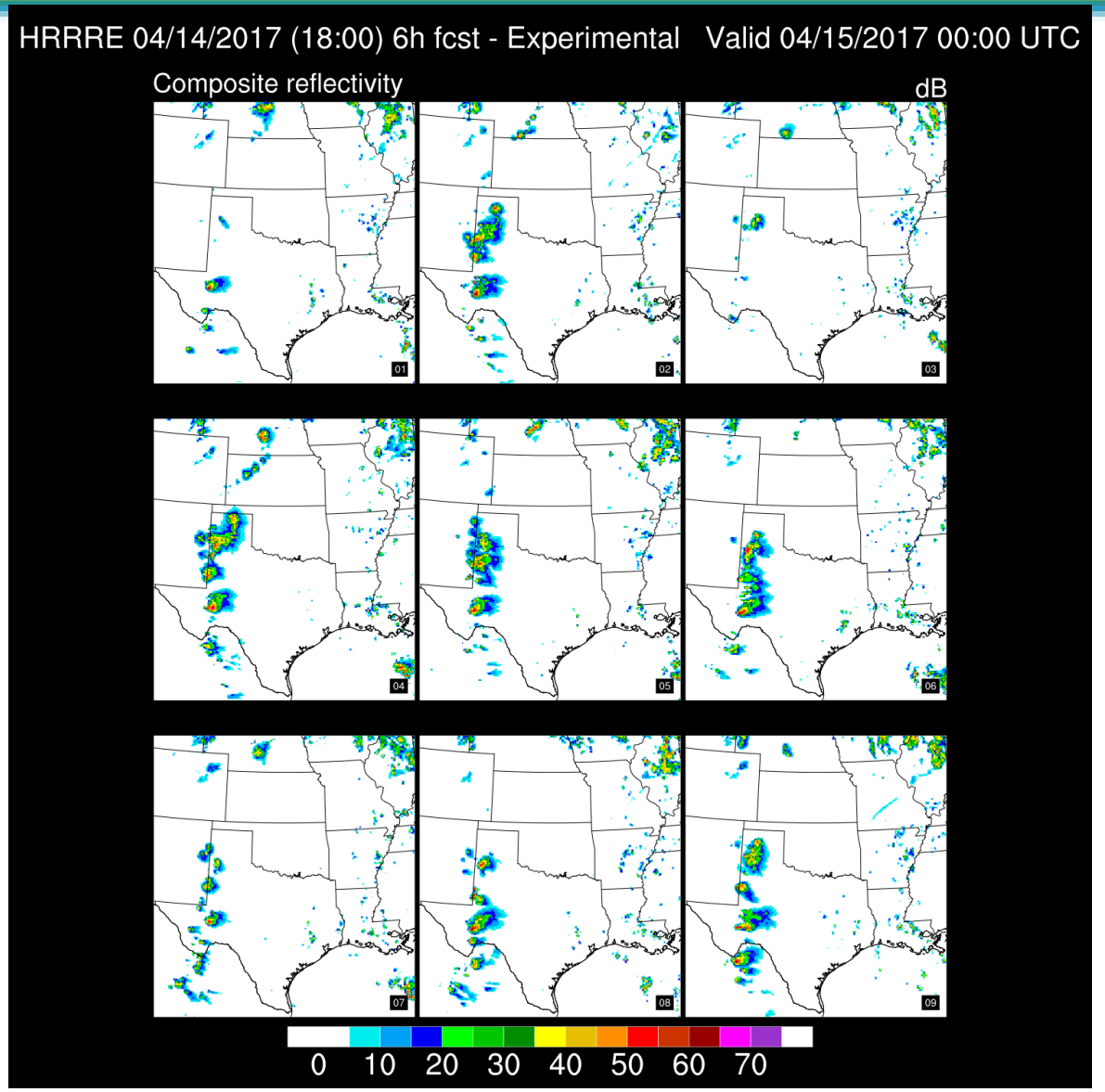




More Accurate Convection with CAM Ensemble DA in 0-6 hrs

Deterministic HRRR 6-hr Forecast





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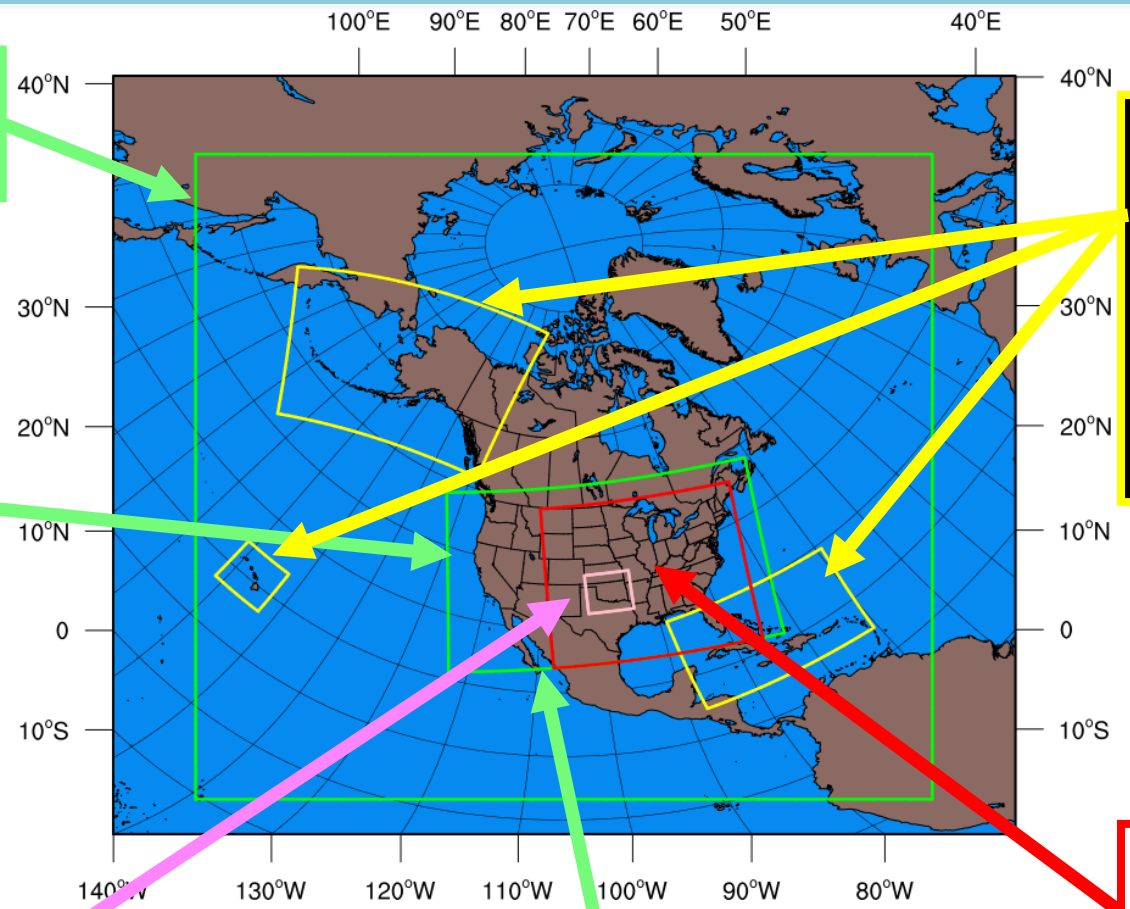

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